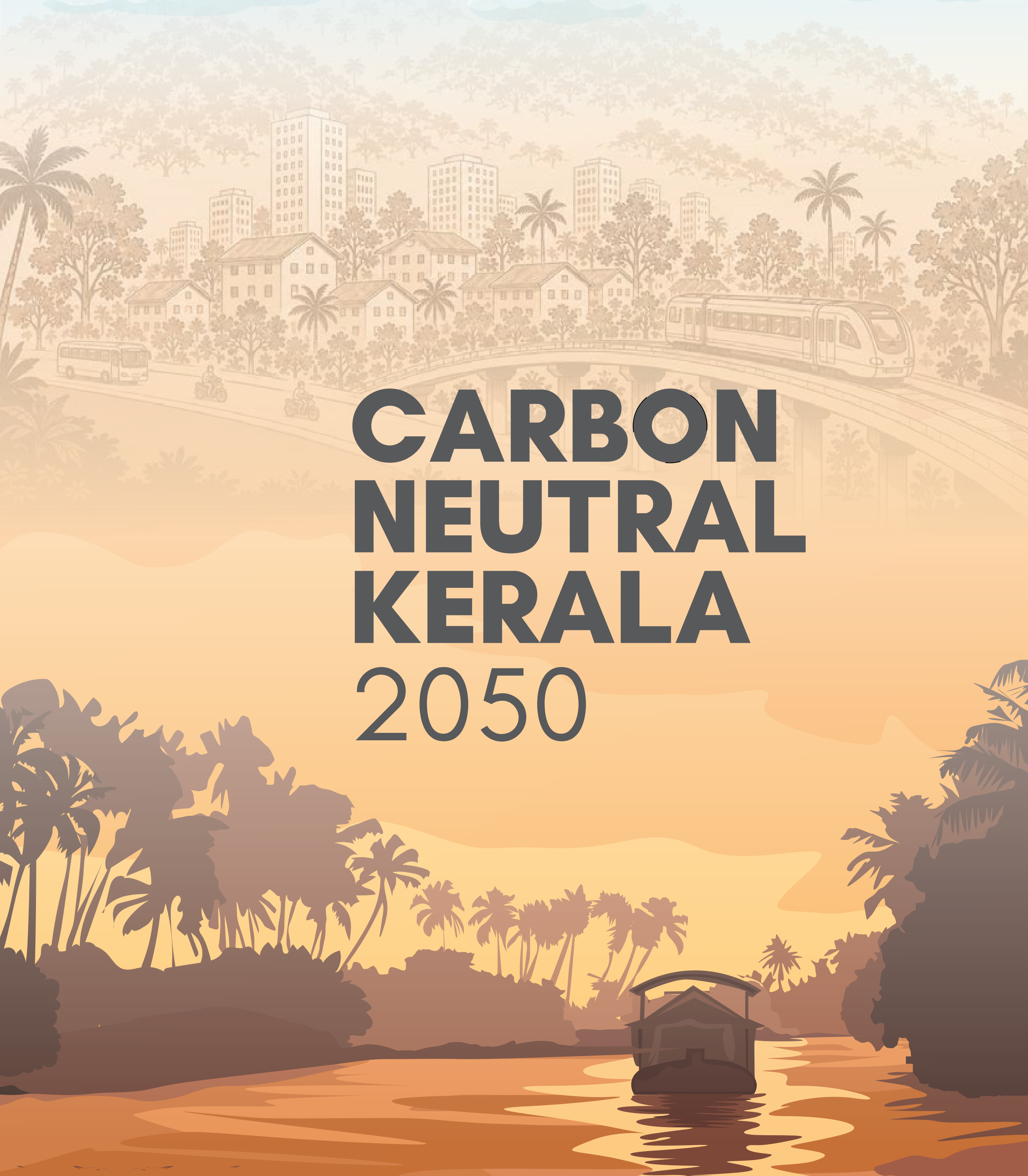
VASUDHA
FOUNDATION
Green ways for a good earth!

DIRECTORATE OF ENVIRONMENT
AND CLIMATE CHANGE
Department of Environment
Government of Kerala



CARBON NEUTRAL KERALA 2050

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CARBON NEUTRAL KERALA 2050

JUNE 2026

Directorate of Environment & Climate Change
F-IV KSRTC Terminal Complex
Thiruvananthapuram-01, Kerala

www.climatechange.envt.kerala.gov.in
www.envt.kerala.gov.in

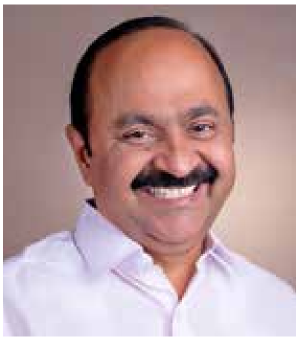
The Directorate of Environment and Climate Change (DoECC), Department of Environment, Government of Kerala, is the nodal agency for planning, coordinating, and overseeing the implementation of environment and climate change policies and programmes of both the Central and State Governments.

Kerala Carbon Neutral Pathway 2050

Kerala State Action Plan on Climate Change 2023-30 Implementation

Priority Intervention
Outcome 6: State-wide climate data collection and database systems established
Project/Objective-6: Climate Change Monitoring and Database Management

Citation: DoECC and Vasudha Foundation, 2026. Kerala Carbon Neutral Pathway 2050, Directorate of Environment and Climate Change, Department of Environment, Government of Kerala.



GOVERNMENT OF KERALA

V. D. SATHEESAN

Chief Minister

Kerala's long-term development aspirations can be achieved through the integration of climate resilience and sustainability into planning and decision-making, while safeguarding our natural resources and ecological wealth. This calls for scientifically informed strategies and systematic planning.

The Kerala State Action Plan on Climate Change 2023-30 and the State's greenhouse gas inventory provide a strong policy and scientific foundation for guiding climate action in Kerala. While India has committed to achieving net-zero emissions by 2070, Kerala's Carbon Neutral 2050 pathway advances this vision by two decades, positioning the State as a leading example of subnational climate leadership. Building on these efforts and commitments, the pathway presents a long-term vision and strategic roadmap to guide Kerala's transition towards a sustainable, low-carbon, and climate-resilient future.

The pathway provides a framework for reducing greenhouse gas emissions across key sectors while advancing the transition towards clean and sustainable energy architecture. Its successful implementation will require institutional commitment, inter-departmental coordination, and active participation from all stakeholders.

I congratulate the Environment Department, Government of Kerala, for formulating the Carbon Neutral Kerala 2050 pathway through a scientific and consultative process. I am confident that this pathway will serve as an important guide for advancing climate action and sustainable development in the State.

V. D. Satheesan

GOVERNMENT OF KERALA

SUNNY JOSEPH

Minister For Electricity, ANERT, Environment, Parliamentary Affairs

Kerala is a progressive State that has consistently adopted policy-driven and scientifically informed approaches for social advancement through coordinated institutional and societal efforts, while also proactively addressing climate change through integrated planning and action. The Kerala State Action Plan on Climate Change 2023-30 and the State's greenhouse gas inventory have provided a strong foundation for informed climate policy and action.

Building on these efforts, the Carbon Neutral Kerala 2050 pathway presents a comprehensive framework to support the State's transition towards a sustainable, climate-resilient, and environmentally responsible future. A major focus of the pathway is the transition towards 100% renewable energy by 2040 through the large-scale deployment of solar and wind energy, expansion of energy storage systems, grid modernisation, decentralised renewable energy generation, and increased electrification across sectors. The pathway also highlights sustainable mobility, energy efficiency, green hydrogen adoption, industrial decarbonisation, scientific waste management, and the enhancement of carbon sequestration through land-based interventions to reduce dependence on fossil fuels and support long-term climate resilience and energy security in the State.

The Government remains committed to supporting these efforts through the appropriate policy measures, institutional mechanisms, and collaborative partnerships to further advance Kerala's climate goals and sustainable development aspirations.

I congratulate Sri Suneel Pamidi, IFS, Director, Directorate of Environment and Climate Change, and his team, along with all the institutions, experts, and stakeholders who contributed to the preparation of this pathway.

Sunny Joseph

GOVERNMENT OF KERALA

SEERAM SAMBASIVA RAO, IAS

Special Secretary to Government,
Electronics & Information Technology, Environment Department

The Carbon Neutral Kerala 2050 pathway reflects the State's commitment to pursuing climate action through informed policy planning, scientific assessment, and coordinated institutional efforts. Prepared through a rigorous process of sectoral assessments, stakeholder consultations, and inter-departmental engagement, this document provides a comprehensive framework to guide the State's transition towards a low-carbon and climate-resilient future.

The Environment Department and the Directorate of Environment and Climate Change have played a central role in steering this process - from constituting and convening the inter-departmental Working Group that brought together key stakeholder departments, to coordinating sectoral assessments, facilitating technical inputs, and ensuring alignment with the State's broader development priorities. This institutional framework, built around cross-departmental collaboration, will continue to serve as the backbone of implementation going forward. The Department remains committed to leading this effort by driving sustained coordination, establishing effective monitoring frameworks, and ensuring convergence across Government programmes to translate the pathway's recommendations into measurable outcomes on the ground.

The insights presented in this document will serve as a valuable reference for climate-responsive planning and decision-making across sectors and provide a strong foundation for integrating climate considerations into the State's future development strategies.

On behalf of the Environment Department, Government of Kerala, I extend my sincere gratitude to the Vasudha Foundation for its partnership in preparing this pathway. I also place on record my appreciation for the valuable contributions of various Government departments, research institutions, and stakeholder organisations whose engagement was instrumental in shaping this pathway.

I congratulate Sri. Suneel Pamidi IFS, and his team at the Directorate of Environment and Climate Change for their committed efforts and valuable contributions towards the successful formulation of the Carbon Neutral Kerala 2050 pathway.

Seeram Sambasiva Rao, IAS

GOVERNMENT OF KERALA

SUNEEL PAMIDI, IFS

Director, Directorate of Environment & Climate Change

Climate change is no longer solely an environmental concern; it is increasingly shaping the way we plan development, manage natural resources, ensure energy security, and safeguard livelihoods. For a State like Kerala, which is highly vulnerable to climate impacts yet endowed with rich natural and human resources, addressing this challenge requires informed policy decisions supported by scientific evidence and long-term planning. Recognising this imperative, Kerala has adopted a proactive approach to climate governance through the Kerala State Action Plan on Climate Change (KSAPCC) 2023-30, which provides the overarching framework for strengthening climate resilience and advancing low-carbon development.

Building upon this foundation, the Directorate of Environment and Climate Change prepared the State Greenhouse Gas Inventory to establish a scientific understanding of Kerala's emission profile and identify key emission sources. The Carbon Neutral Kerala 2050 Pathway represents the next important step in this continuum of climate action and provides a long-term roadmap for achieving the State's carbon neutrality vision.

Prepared in partnership with the Vasudha Foundation, the pathway is the outcome of extensive sectoral assessments, energy system modelling, stakeholder consultations, and inter-departmental coordination. The contributions of Government departments, research institutions, experts, industry representatives, and local self-governments have been invaluable in shaping a pathway that is both scientifically robust and aligned with Kerala's developmental aspirations.

The pathway identifies practical and achievable measures through which Kerala can achieve carbon neutrality while ensuring economic growth, energy security, environmental sustainability, and social well-being. The assessment highlights that the State's transition will be driven primarily by the transformation of the energy sector through electrification, renewable energy deployment, improvements in energy efficiency, adoption of green hydrogen in hard-to-abate sectors, and modernisation of the electricity system. Sustainable mobility, low-carbon industrial development, scientific waste management, climate-responsive agriculture, and enhanced carbon sequestration through natural ecosystems are also important components of this transition.

The successful implementation of this pathway will require sustained collaboration among Government departments, institutions, industry, academia, local self-governments, and communities. The Directorate of Environment and Climate Change, through its Climate Change Cell, will continue to facilitate coordinated climate action, technical support, and the integration of climate considerations into development planning and decision-making.

I sincerely thank the Vasudha Foundation for its valuable partnership and technical support in preparing this pathway. I also place on record my appreciation to all departments, institutions, experts, and stakeholders whose contributions were instrumental in shaping this document.

Finally, I congratulate the officers of the Directorate of Environment and Climate Change for their contributions to the successful development of the Carbon Neutral Kerala 2050 Pathway. I am confident that this document will serve as a guiding framework for advancing Kerala's climate action and sustainable development.

Suneel Pamidi, IFS

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Abbreviations

AAI	Airport Authority of India
AC	Air Conditioner
ACMA	Automotive Component Manufacturers Association
AGL	Above Ground Level
AI	Artificial Intelligence
ANERT	Agency for New and Renewable Energy Research and Technology
ANR	Assisted Natural Regeneration
ASI	Annual Survey of Industries
ATF	Aviation Turbine Fuel
AWD	Alternate Wetting and Drying
BAU	Business-as-Usual
BEE	Bureau of Energy Efficiency
BESS	Battery Energy Storage System(s)
BLDC	Brushless Direct Current
BMS	Battery Management System(s)
BOD	Biochemical Oxygen Demand
BOOT	Build-Own-Operate-Transfer
BPCL	Bharat Petroleum Corporation Limited
BPKM	Billion Passenger Kilometres
BPKP	Bharatiya Prakritik Krishi Padhathi
BTKM	Billion Tonne Kilometres
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CCJ	Kozhikode International Airport
CCUS	Carbon Capture, Utilisation and Storage
CEA	Central Electricity Authority
CEQMS	Continuous Effluent Quality Monitoring System(s)
CFL	Compact Fluorescent Lamp(s)
CGD	City Gas Distribution
CH_4	Methane
CIAL	Cochin International Airport Limited
CN50	Carbon Neutral Kerala by 2050
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide

CO_2e	Carbon Dioxide Equivalent
COP	Conference of Parties
COP26	26th Conference of the Parties
CPCL	Chennai Petroleum Corporation Limited
CPP	Captive Power Plant(s)
CSD	Carbon Stock Density
CTO	Consent to Operate
CUF	Capacity Utilisation Factor
DC	Direct Current
DEWATS	Decentralised Wastewater Treatment Systems
DG	Diesel Generator
ECBC	Energy Conservation Building Code
EFOM	Energy Flow Optimisation Model
EMC	Energy Management Centre
EPI	Energy Performance Index
ESDM	Electronic System Design and Manufacturing
ETSAP	Energy Technology Systems Analysis Program
EV	Electric Vehicle
FACT	Fertilisers and Chemicals Travancore Limited
FAME	Faster Adoption and Manufacturing of Electric Vehicles
FCEV	Fuel Cell Electric Vehicle
FPO	Farmer Producer Organisation
FSTP	Faecal Sludge Treatment Plant(s)
GCA	Gross Cropped Area
GDP	Gross Domestic Product
GH_2	Green Hydrogen
GHG	Greenhouse Gas
GP	Gram Panchayat
GPS	Global Positioning System
GRIHA	Green Rating for Integrated Habitat Assessment
GSDP	Gross State Domestic Product
GSVA	Gross State Value Added

GVA	Gross Value Added
GWh	Gigawatt Hour
GW	Gigawatt
HGV	Heavy Goods Vehicle
HSD	High Speed Diesel
HVAC	Heating, Ventilation and Air Conditioning
HVIC	Hydrogen Valley Innovation Cluster
HYV	High Yield Variety
ICE	Internal Combustion Engine
ICED	India Climate & Energy Dashboard
IEA	International Energy Agency
IMA	Intermittent Multiple Aeration
INM	Integrated Nutrient Management
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
IREP	Integrated Refinery Expansion Project
IRES	India Residential Energy Survey
ISA	Intermittent Single Aeration
ISO	International Organization for Standardization
IT	Information Technology
KERA	Kerala Climate Resilient Agri-Value Chain Modernization
KIAL	Kannur International Airport Limited
KIED	Kerala Institute for Entrepreneurship Development
KMML	Kerala Minerals and Metals Limited
KMRL	Kochi Metro Rail Limited
KSEB	Kerala State Electricity Board
KSIE	Kerala State Industrial Enterprises
KSINC	Kerala State Inland Navigation Corporation
KSPCB	Kerala State Pollution Control Board
KSRTC	Kerala State Road Transport Corporation
KSS	Kochi Sewerage Scheme
KSWTD	Kerala State Water Transport Department
kt	Kilotonnes
$ktCO_2e$	Kilotonnes of Carbon Dioxide Equivalent
KWA	Kerala Water Authority
LDO	Light Diesel Oil
LED	Light Emitting Diode
LGV	Light Goods Vehicle
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LULUCF	Land Use, Land-Use Change and Forestry
MATSYAFED	Kerala State Co-operative Federation for Fisheries Development Limited
MCM	Million Cubic Metres
MDF	Moderately Dense Forest
MILMA	Kerala Co-operative Milk Marketing Federation
MJ	Megajoule
MLD	Million Litres per Day
MMSCM	Million Standard Cubic Metre
MMT	Million Metric Tonnes
MMTPA	Million Metric Tonnes Per Annum
MNTKM	Million Net Tonne Kilometres
MRV	Monitoring, Reporting and Verification
MSME	Micro, Small and Medium Enterprises
MSW	Municipal Solid Waste
MT	Metric Tonne
$MtCO_2e$	Million Tonnes of Carbon Dioxide Equivalent
MU	Million Units
N_2O	Nitrous Oxide
NABARD	National Bank for Agriculture and Rural Development
NECP	National Energy Cooking Program
NFHS	National Family Health Survey
NG	Natural Gas
NSDC	National Skill Development Corporation
NTKM	Net Tonne Kilometres
NTPC	National Thermal Power Corporation
NUE	Nitrogen Use Efficiency
PCE	Pollution Control Equipment

PDMC	Per Drop More Crop
PDPP	Propylene Derivatives Petrochemical Project
PE	Provincial Estimates
PEG	Public Electricity Generation
PJ	Petajoule
PLF	Plant Load Factor
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana
PMMSY	Pradhan Mantri Matsya Sampada Yojana
PMU	Programme Management Unit
PNG	Piped Natural Gas
PPAC	Petroleum Planning and Analysis Cell
PPA	Power Purchase Agreement
PV	Photovoltaic
QE	Quick Estimates
RBP	Ration Balancing Program
RE	Renewable Energy
RTS	Rooftop Solar
SAF	Sustainable Aviation Fuel
SAPCC	State Action Plan on Climate Change
SBSAP	State Biodiversity Strategy and Action Plan
SCM	Standard Cubic Metre
SDB	Sludge Drying Beds
SIAM	Society of Indian Automobile Manufacturers
SIDBI	Small Industries Development Bank of India
SLBC	State Level Bankers' Committee
SOC	Soil Organic Carbon
STP	Sewage Treatment Plant(s)
SRT	Solids Retention Time
SWIFT	Single Window Interface for Fast and Transparent Clearance
SWTD	State Water Transport Department
TIMES	The Integrated MARKAL-EFOM System
TMT	Thousand Metric Tonnes
TOW	Total Organically Degradable Material in Wastewater
TPA	Tonnes Per Annum
TPES	Total Primary Energy Supply
TRV	Thiruvananthapuram International Airport
TSS	Thiruvananthapuram Sewerage Scheme
TWh	Terawatt Hour
UE	Useful Energy
UGD	Underground Drainage
VAHAN	Vehicle Registration Database / VAHAN Dashboard
ZLD	Zero Liquid Discharge

Tea Plantation, Munnar, Kerala

Executive Summary

Strategic Vision and Policy Context

The State, renowned for its rich biodiversity and high human development, has set a transformative target of achieving 100% reliance on renewable energy (RE) by 2040 and carbon neutrality by 2050 (CN50). By pursuing these goals, Kerala aims to achieve net-zero emissions well ahead of India's national 2070 target through a sustained energy transition and deep emission reductions across key emitting sectors, with natural carbon sinks playing a significant role in addressing residual emissions.

Although the State currently maintains a comparatively low-emission profile, with per capita emissions of 0.64 tCO_2e compared to the national average of 2.46 tCO_2e, sustaining this advantage and progressing towards carbon neutrality will require a comprehensive and transformative decarbonisation pathway.

In this context, the CN50 Pathway envisions a major transition from a thermal power import-dependent energy system to a renewable energy architecture supported by large-scale energy storage, grid modernisation, and distributed clean energy systems.

Vizhinjam International Seaport, Kerala

Emission Profile – The Baseline

Primarily due to State's rich biodiversity and lack of large greenhouse gas-emitting industries, production-based carbon footprint in Kerala is relatively low, though in terms of consumption, its carbon footprint is comparatively high. This becomes evident from the 2021 GHG profile of the State, in which industries (including CPP) and agriculture energy use contributed 11.34% (2.52 $MtCO_2e$) and 0.52% (0.12 $MtCO_2e$) of total gross[1] GHG emissions (22.18 $MtCO_2e$), in contrast to transport and buildings, that were responsible for 49.46% (10.97 $MtCO_2e$) and 16.90% (3.75 $MtCO_2e$) of the gross GHG emissions, respectively. IPPU contributed 5.94% (1.32 $MtCO_2e$), waste 8.66% (1.92 $MtCO_2e$), and agriculture (non-energy) sources contributed to 7.05% (1.56 $MtCO_2e$). About 65.95% (14.63 $MtCO_2e$) of these emissions were offset by land-based removals, highlighting the significance of Kerala's rich forest and other natural ecosystems.

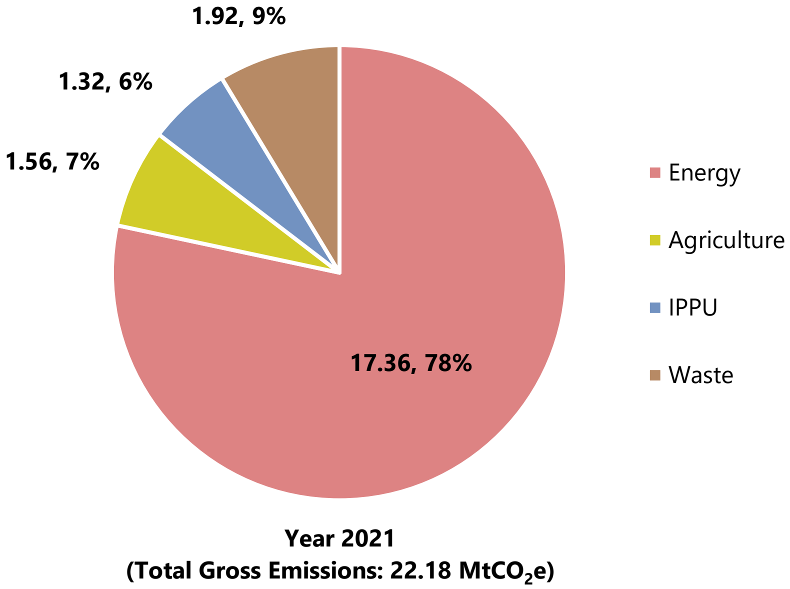


Figure ES1: *Gross emissions (in $MtCO_2e$) in year 2021, Kerala*

Scenario Framework: BAU and CN50

The transition is evaluated across two trajectories, emphasising the necessity of radical policy shifts over incremental adjustments.

- **Business-as-Usual (BAU):** Assumes growth aligned with current trajectories (e.g., EV Policy 2019), consistent efficiency levels, and continued reliance on LPG/biomass for thermal needs.
- **Carbon Neutral (CN50):** Mandates deep electrification, rapid adoption of Green Hydrogen and aggressive deployment of storage technologies to eliminate fossil fuel reliance.

1 In the GHG inventory, gross emissions (22.16 $MtCO_2e$) excluded emissions and removals from the Land category, with land-related contributions considered only in the net emissions estimates. In the CN50 pathway, the Land category has been included in the gross emissions estimates (22.18 $MtCO_2e$) to provide a more comprehensive and consistent representation of total sectoral emissions across the scenario projections.

Table ES1: Energy and Emission Comparison of BAU and CN50		
Metric	**Business-as-Usual (BAU) 2050**	**Carbon Neutral (CN50) 2050**
Total Energy Demand (PJ)	648.04	602.75
Electricity Demand (TWh)	92.54	123.70
Residual Emissions ($MtCO_2e$)	25.90	11.52

Power Sector Transformation

Achieving the 100% RE by 2040 target requires a structural transformation of Kerala's electricity system. The State must transition from a thermal power import-dependent system to a diversified renewable energy portfolio supported by energy storage, grid modernisation, and strategic renewable power procurement arrangements.

- **Electricity Demand Projection:** Electricity demand is projected to increase to **123.70 TWh** by 2050 under the CN50 scenario.
- **Required Capacity:** To ensure reliability, the State must facilitate **50.52 GW of Solar** and **11.28 GW of Wind** capacity.
- **Storage & Flexibility:** A strategic imperative is the deployment of **21 GW / 153 GWh of energy storage** (7.3-hour average duration) to support renewable energy integration and system reliability.
- **Structural Constraints:** As internal RE potential is limited to 18.92 GW, long-term inter-state RE trade agreements are a permanent structural necessity for energy security.
- **Grid Intensity:** The Grid Emission Factor must be driven from 0.58 $kgCO_2e/kWh$ (2021) to near-zero by 2040.

Sectoral Decarbonisation Strategies: Energy

Transport: The total projected electricity demand from the transport sector (road, rail, and water transport) is estimated at 23.82 TWh by 2050, of which the road transport sector alone is expected to account for 21.62 TWh.

- **Light-Duty & Public Transit:** 100% electrification for new sales of 2W, 3W, 4W, and LGVs; 90% for buses.
- **Heavy Freight:** 65% electrification of HGVs, with the remaining 35% of sales transitioning to Green Hydrogen via FCEV or GH_2-ICE technology.

Buildings & Industry

- **Thermal Transition:** 50% of cooking demand must shift to electric induction, with 45% served by Piped Natural Gas (PNG) as a transition fuel.
- **Industrial Feedstocks:** 100% replacement of natural gas with Green Hydrogen in fertilizer (ammonia) production and the adoption of electric heating/plasma generators for process heat.

Sectoral Decarbonisation Strategies: Non-Energy

Industrial Processes and Product Use (IPPU): Emissions from the IPPU sector are primarily driven by ammonia production in the fertiliser industry and are projected to remain at 1.32

$MtCO_2e$ under the BAU scenario.

- **Industrial Feedstock Transition:** Complete replacement of natural gas with Green Hydrogen in ammonia production can abate 0.72 $MtCO_2e$ emissions by 2050, reducing sectoral emissions to 0.60 $MtCO_2e$ and supporting low-carbon industrial transformation.

Agriculture and Waste Sectors: Emissions from the Agriculture and Waste sector are mainly driven by non-CO_2 gases such as methane (CH_4) and nitrous oxide (N_2O), forming a significant share of Kerala's emissions profile (more than 40% of net emissions and ~16% of gross emissions). Non-CO_2 emissions were ~3,485 $ktCO_2e$ in 2021. The key contributors to the emissions are domestic wastewater (~53%), livestock (32%) and agriculture soils (~7%) and these emissions are projected to rise to ~4,018 $ktCO_2e$ by 2050 under BAU. Under the CN50 scenario, targeted interventions, including improved waste management systems, improved livestock feed and manure management, and sustainable agriculture measures, can reduce non -CO_2 emissions by ~57%, bringing them down to ~1,723 $ktCO_2e$ by 2050. It is important to recognise that the non-CO_2 emissions reduction strategies deliver large development benefits as well, such as improved farm productivity, enhanced animal health, better waste management, and overall community wellbeing.

Agriculture: The State will transition toward sustainable practices to reduce projected sectoral emissions by 36.72% by 2050. Key interventions include:

- **Methane Mitigation:** Shifting 84% of paddy cultivation to intermittent multiple aeration and achieving an 80% adoption rate for methane-suppressing feed additives in livestock.
- **Nutrient Management:** Mandating 100% replacement of conventional urea with enhanced efficiency fertilisers such as nano-urea, and transitioning to 50% organic fertilisers to halve emissions from agricultural soils.
- **Efficiency and Sequestration:** Scaling balanced rationing (90% target) and biogas manure management (75%) while promoting organic mulching and micro-irrigation to enhance soil carbon and reduce pumping energy

Waste Management: Treating the waste sector is a prerequisite for achieving carbon neutrality by 2050, as domestic wastewater accounts for 95.53% of emissions within the waste sector.

- **Strategic Mandate (Approach 3):** The State must establish 194 MLD of centralised aerobic treatment capacity in dense urban centers.
- **Rural Clusters:** Deploy household-level septic tanks integrated with cluster-level Faecal Sludge Treatment Plants (FSTPs) to ensure 100% treatment by 2050.

Enhancing Sequestration Potential of Land and Blue Carbon

The State aims to increase annual carbon sequestration from 14.63 $MtCO_2e$ to 23.91 $MtCO_2e$ by 2050 through a strategic expansion of natural sinks.

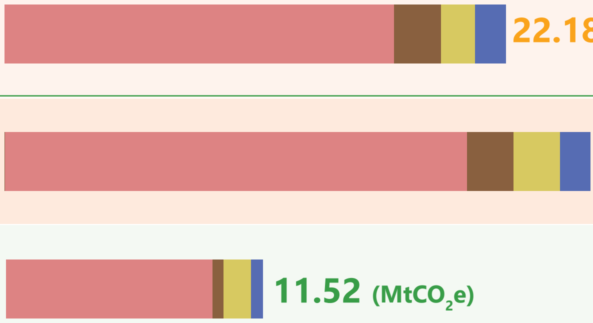
- **Blue Carbon Restoration:** Expanding mangrove cover from the current 21.15 sq. km to 100.60 sq. km, adding 1,237 $ktCO_2e$ of annual sequestration potential.
- **Agroforestry Expansion:** Bringing 75% of the state's barren and fallow land (~630 sq. km) under productive green cover through social and agroforestry.
- **Forest Density:** Enhancing carbon stock density in existing forests to strengthen carbon sequestration while supporting biodiversity conservation and soil health.

Together, these interventions are projected to increase carbon sequestration to 23.91 $MtCO_2e$ by 2050, enabling the State to offset residual emissions projected under the CN50 scenario and achieve net negative emissions by 2050.

KERALA CARBON NEUTRAL PATHWAY 2050

Kerala's carbon-neutral pathway is shaped by its rich biodiversity, strong natural carbon sinks, and service-oriented economy. With forests and ecosystems playing a significant role in moderating the State's emissions footprint, the greatest opportunity lies in advancing the energy transition through renewable energy, electrified transport, efficient buildings, and clean technologies.

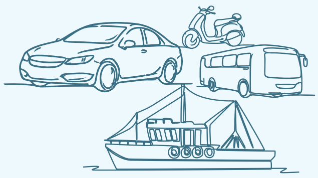
	GROSS EMISSIONS	SEQUESTRATION	NET EMISSIONS
2021	22.18 ($MtCO_2e$)	-14.63 ($MtCO_2e$)	7.55 ($MtCO_2e$)
BAU 2050	25.90 ($MtCO_2e$)	-14.63 ($MtCO_2e$)	11.27 ($MtCO_2e$)
CN50	11.52 ($MtCO_2e$)	-23.91 ($MtCO_2e$)	-12.40 ($MtCO_2e$)



ENERGY WASTE AGRICULTURE IPPU

SECTORAL POTENTIAL (2050)

TRANSPORT



- 100% EV share in new sales of 2Ws, 3Ws and 4Ws
- Addition of ~53,000 e-buses to the stock
- Electrification of fishing boats
- Electrification of long-haul trucks

AMP[1]: 7.21 $MtCO_2e$
(27.83% of gross emissions)

BUILDINGS

- 50% cooking demand met through e-cookstoves
- 41 lakh HH[2] shift from LPG to PNG
- Adoption of 3-5 star EE[3] cooling solutions

AMP: 2.56 $MtCO_2e$
(9.90% of gross emissions)

AGRICULTURE

- Adoption of 16,000 electric/solar pumps by 2030, and 20,000 e-tractors by 2050
- Livestock: Improved feed (80%) and manure management (75%)
- Organic inputs (50%) + Enhanced efficiency fertilizers (25%)
- Transition to climate-smart rice systems (AWD[4], SRI[5], and DSR[6])

AMP: 0.90 $MtCO_2e$
(3.46% of gross emissions)

1. AMP: Annual Mitigation Potential 2. HH: Households 3. EE: Energy-Efficient 4. AWD: Alternate Wetting and Drying 5. SRI: System of Rice Intensification

IN ALIGNMENT WITH:

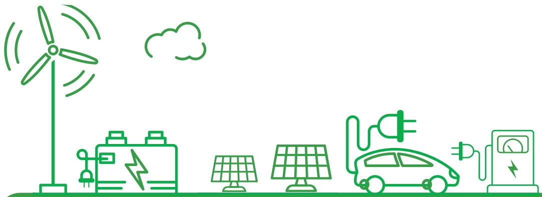
Sustainable Development Goals

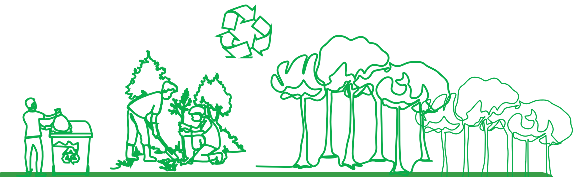
Livelihood Resilience

Energy Security

Circular Economy

BIG PICTURE
Carbon neutrality by 2050 and 100% Renewable Energy by 2040





Annual Mitigation Potential
14.38 $MtCO_2e$
(55.54% of gross emissions)

Annual Sequestration Potential
23.91 $MtCO_2e$
(92.33% of gross emissions)

123.70 TWh Electricity Demand

50.52 GW Solar Capacity

11.28 GW Wind Capacity

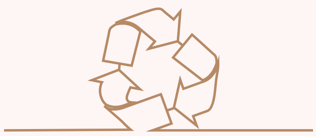
21 GW / 153 GWh Energy Storage Capacity

INDUSTRY & IPPU[7]

- Electrification of 60% of industrial heating
- Green hydrogen use for ammonia production, mobility, the marine sector, and long-haul trucks
- 100% RE[8] based captive power generation

AMP: 2.17 $MtCO_2e$
(8.36% of gross emissions)

WASTE



- Domestic Wastewater
  - Faecal sludge management for existing and proposed STP[9], and 194 MLD centralised treatment in urban areas
  - Household-level septic tanks with 176 FSTPs[10]
- 100% industrial wastewater treatment through ETPs[11]

AMP: 1.54 $MtCO_2e$
(5.93% of gross emissions)

CARBON SEQUESTRATION

- Sustain annual net increase in forest carbon stock to maintain baseline sequestration: 14.63 $MtCO_2e$.
- Enhance CSD[12] of existing forests
- Expand mangrove cover from 21.15 sq. km to 100.60 sq. km
- Agro forestry in 630 sq. km of barren/fallow land

ASP[13]: 23.91 $MtCO_2e$
(92.33% of gross emissions)

6. DSR: Direct Seeded Rice
7. IPPU: Industrial Processes and Product Use
8. RE: Renewable Energy
9. STP: Sewage Treatment Plant
10. FSTPs: Faecal Sludge Treatment Plants
11. ETP: Effluent Treatment Plants
12. CSD: Carbon Stock Density
13. ASP: Annual Sequestration Potential

Solar Panels, Cochin International Airport, Kerala

Part I

Introduction, Context and Methodology

Chapter 1

Context & Objective

The rising global average temperatures, driven by the escalating concentration of greenhouse gases resulting from human activities, are profoundly altering the natural environment. This trend is exacerbating natural hazards and increasing the occurrence of disasters, leading to widespread consequences such as coastal flooding, intensified storms, wildfires, and droughts. To address this, 197 parties (including 196 countries and the European Union), in the Conference of Parties (COP) held in Paris, agreed to limit the global temperature rise to well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the increase to 1.5 degree Celsius.

India announced its commitment to achieve net-zero emissions by 2070 at COP26 in Glasgow in 2021. In alignment with this national objective, Kerala has taken proactive measures to revise its climate and energy policies, aiming to transition its economy toward carbon neutrality. The state has set ambitious targets to become 100% reliant on renewable energy by 2040 and to achieve carbon neutrality by 2050, thereby surpassing the national timeline.

From the standpoint of GHG emissions, Kerala accounted for a net GHG emissions of 7.55 $MtCO_2e$. Despite comprising 2.65% of India's population (GHG Platform India, 2018), Kerala exhibits a significantly lower per capita emission rate of 0.64 tCO_2 compared to the national average of 2.46 tCO_2 (Government of Kerala (C), 2026). This notable difference primarily stems from reduced emissions in the energy sector, especially in electricity usage. For 56.53% of its electricity needs, Kerala relies on thermal electricity sources from neighbouring states. Kerala is uniquely positioned to achieve carbon neutrality, as nearly 65.95% of its annual gross GHG emissions (22.18 $MtCO_2e$ in 2021) are offset by the forest alone – sequestering approximately 14.63 $MtCO_2e$ in 2021 – highlighting the state's significant natural carbon sequestration potential and its capacity to emerge as a frontrunner in achieving carbon neutrality by 2050.

The State Action Plan on Climate Change (SAPCC 2023-30) of Kerala plays a crucial role in addressing climate change challenges while fostering sustainable development (Government of Kerala (C), 2022). By identifying priority areas such as renewable energy, resilient agriculture, and coastal protection, the SAPCC offers a strategic framework for policy formulation and immediate implementation.

The Directorate of Environment and Climate Change, Government of Kerala, in partnership with the Vasudha Foundation has undertaken this assessment aimed at proposing sector-specific policy interventions for transitioning towards a low-carbon economy and achieving carbon neutrality in the State by 2050. The assessment provides an in-depth analysis of key emitting sectors and outlines potential pathways to carbon neutrality. Employing a comprehensive approach, it analyses current and historical emissions, evaluates the energy mix, projects future energy trajectories at the sectoral level, and presents a holistic decarbonisation plan tailored to the State's specific needs. In addition, the assessment includes a focused analysis of the electricity sector, detailing targeted decarbonisation strategies aimed at achieving carbon neutrality in the State's electricity needs.

Approach to Kerala Carbon Neutral Pathway 2050 Development

The formulation of the Carbon Neutral Kerala 2050 pathway was undertaken through an iterative and consultative process involving key state departments, sectoral agencies, technical institutions, and domain experts. Three major stakeholder consultations were held with the participation of 84 representatives across 40 stakeholder departments, organisations and institutions. In addition, a series of stakeholder consultation meetings and inter-departmental discussions were conducted to validate assumptions, refine sectoral pathways, and ensure alignment with existing policies and implementation realities. Inputs from these consultations were systematically incorporated into the modelling framework and policy recommendations, ensuring that the proposed pathway is both technically robust and institutionally feasible.

Methodology

1. GHG Inventory

To assess the historical greenhouse gas (GHG) emissions of the State, the methodology outlined by the Intergovernmental Panel on Climate Change (IPCC) for GHG emission inventory has been adopted. This approach involves collating data from various sectors contributing to emissions, such as energy, industry, agriculture, waste and forest and applying emission factors and activity data to calculate total GHG emissions (Government of Kerala (C), 2026).

2. Energy Demand and Emission Projections

The projected energy use and its associated emissions to 2050 are derived from The Integrated MARKAL-EFOM System (TIMES) model (The TIMES Model, n.d.), which is a bottom-up model generator that uses linear programming to optimise and derive a least-cost energy system. The model balances energy demand and supply across multiple sectors, taking account of a wide range of fuels and energy technologies across the scenarios framed for this analysis. These sectors include buildings, agriculture, transportation, services and industry. Further, a capacity expansion power system model is developed using PyPSA (Python for Power System Analysis, n.d.) to estimate the electricity supply mix of Kerala by 2050. This is discussed in detail in the subsequent sections.

3. Sectoral GHG Abatement and Sequestration Potential Assessment

To assess sectoral GHG abatement potential, a comprehensive evaluation has been undertaken across the principal emitting sectors, including transport, industry, buildings, agriculture, and waste management. In the transport sector, mitigation options such as the accelerated adoption of electric mobility, the promotion of public and non-motorised transport, and the transition to cleaner fuels have been examined. Within the industrial sector, opportunities for emission reduction have been assessed through improvements in energy efficiency, fuel switching to low-carbon alternatives, process optimisation, and increased reliance on renewable energy sources.

Similarly, in the buildings sector, the assessment has focused on enhancing energy performance through widespread use of energy-efficient appliances (LED lights, 3/5 star ACs, etc.), rooftop solar deployment, and adherence to green building standards. The agricultural sector assessment has explored pathways for reducing both energy and non-energy related emissions through the adoption of solar irrigation pumps, electric trucks and tillers, precision farming, improved fertiliser management, promotion of organic farming practices, and better livestock management to curb methane and nitrous oxide emissions. In addition, mitigation measures in the waste sector, such as setting up Fecal Sludge Treatment Plants (FSTPs), Sewage Treatment Plants (STPs), Underground Drainage (UGD) systems for treating domestic wastewater, and establishing Effluent Treatment Plants (ETPs) along with Continuous Treated Effluent Monitoring Systems for treating industrial wastewater, have been evaluated for their abatement potential.

Apart from sectoral abatements, enhancement of the sequestration potential has also been explored. A comprehensive methodology has been adopted for the carbon sequestration assessment, focusing on evaluating the potential of land-use based and blue carbon interventions. The assessment explores strategies including agroforestry and social forestry, enhancement of carbon stock densities in existing forests. In addition, restoration of mangrove cover has been assessed to strengthen blue carbon sequestration potential along coastal regions.

Scenario Framework

This assessment investigates two scenarios to explore different pathways for energy sector trends and associated emissions up to 2050.

The first scenario, Business as Usual (BAU), depicts energy and non-energy sector demand and supply growth in line with current policies (refer Annexure 1) and historical trajectories, where applicable. In this scenario, improvements in energy efficiency remain consistent with existing levels up to 2050.

Similarly, limited potential for fuel switching persists, primarily through the electrification of road transport supported by initiatives like the FAME and state EV schemes, while households and commercial establishments continue to use LPG and biomass for cooking.

The second scenario, Carbon Neutral by 2050 (CN50), presents a more aggressive outlook aimed at complete decarbonisation across the sectors in the State by 2050 while ensuring energy security. In this scenario, increased electrification of the transport fleet, adoption of clean cooking solutions, and improvements in energy efficiency will significantly reduce fossil fuel demand and associated emissions.

Chapter 2

State Profile

Kerala, situated in the southern region of the Indian Peninsula, is geographically located between the Arabian Sea to the West and the Western Ghats mountain range to the East. Covering a total land area of 38,862.87 sq. km, the state constitutes approximately 1.18% of India's total physiographic region. Agriculture (net area sown) constitutes the largest portion of land use, covering 19,727.70 sq. km, which accounts for 50.76% of the total area (Government of Kerala (B), 2025) (Figure 1). Forestry accounts for 27.83%, while non-agricultural use, fallow land, and other uncultivable land accounts for 15.69%, 2.79% and 2.69% respectively. Barren and uncultivable land accounts for 0.24% only. The extensive network of water bodies in the state occupies 2.60% of the total geographical area (Government of Kerala (A), 2023).

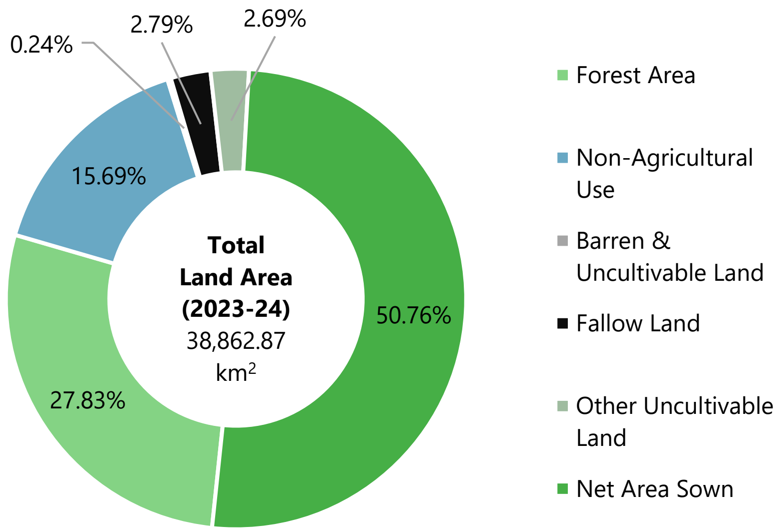


Figure 1: *The land use pattern (sq. km) of Kerala 2023-24*

Source: Kerala Economic Review 2025

Population Projections

As of 2011, Kerala had a population of 33.4 million, distributed across approximately 7.9 million households, with 48% males and 52% females (Government of India, 2011). Of these households, 47% were classified as urban and 53% as rural. However, the share of urban population in the State is projected to rise sharply to 96.40% by 2036 (Government of

Kerala (A), 2025). Furthermore, the State's total population is expected to increase from 33.4 million in 2011 to 40.23 million by 2050 (Table 1).

Although Kerala's total population is expected to continue growing over the years, the annual growth rate is projected to decline gradually. In addition, the number of households is anticipated to rise by 39.2% by 2050, reaching 12.10 million households, up from 7.9 million in 2011.

Table 1: Population and household trends of Kerala

Year	State Population (in millions)	No. of Households (in millions)	No. of persons per household
Census 2001	31.84	6.70	4.75
Census 2011	33.40	7.90	4.23
2021 (projection)	35.49	9.40	3.74
2031 (projection)	36.48	10.50	3.48
2050 (projection)	40.23	12.10	3.30

Source: Census 2001, Census 2011, Population Projections for India and States 2011-2036

Economic Profile

Kerala comprises only 2.76% of India's population and covers just 1.18% of its land area, it makes a substantial contribution of more than 4% to the GDP of India. Over the last decade, Kerala's Gross State Domestic Product (GSDP) grew annually at a growth rate of 4.8% between 2012-13 and 2021-22 (Government of India (D), 2025). In 2022-23, the GSDP, at constant price, increased to Rs. 5.95 lakh crore (QE), from Rs 5.72 lakh crore (PE) in 2021-22, registering growth of 6.6%. The service sector prominently drives Kerala's economy, with a substantial 63.8% share of GSDP in 2022-23 (Government of India (D), 2025). Within this sector, the Information Technology (IT) and tourism industries collectively account for a significant share.

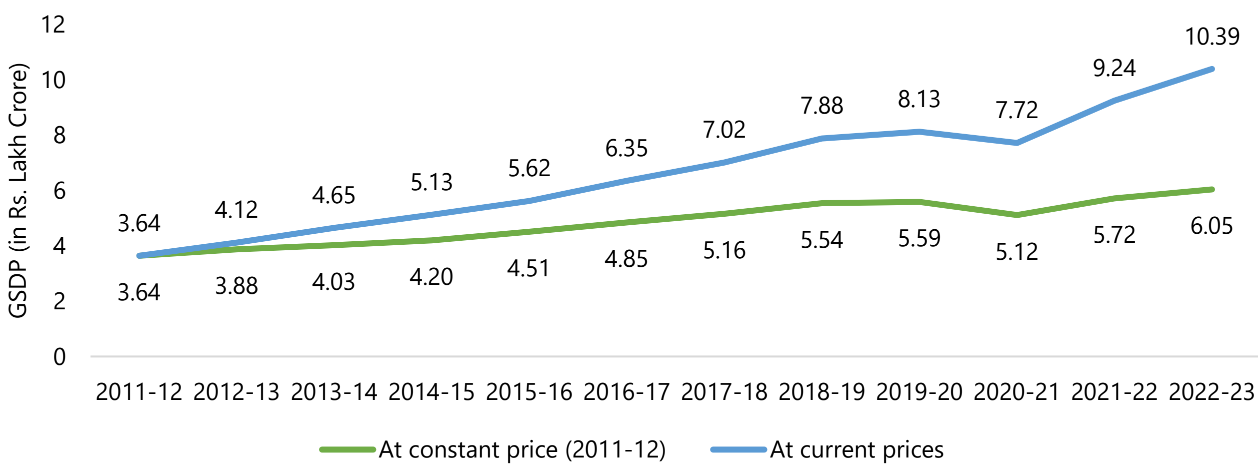


Figure 2: *Kerala's GSDP (Lakh Crore) trend*

Source: India Climate & Energy Dashboard (ICED) (Government of India (C), n.d.)

The IT sector has emerged as a key growth driver, leveraging the State's high literacy rate and skilled workforce. With major hubs such as Technopark (Thiruvananthapuram), Infopark (Kochi) and Cyberpark (Kozhikode), the sector employs nearly one lakh professionals and generated export revenues exceeding ₹11,630 crore in 2022–23 (Government of Kerala (A), 2025). Further, the startup ecosystem has nurtured over 5,000 startups and mobilised around ₹2,000 crore in investments. The state has positioned itself as one of India's leading IT destinations. The tourism sector, contributing nearly 10% to the State's GSDP, capitalises on Kerala's diverse landscapes and rich biodiversity. The agriculture and allied sectors continue to play a foundational role in the State's economy, with Kerala contributing 33.48% of India's coconut (Government of India (A), 2021), 85% of natural rubber, 97% of pepper (State Level Bankers Committee, Kerala, n.d.), and 90% of cardamom production (Gayathri, et al., 2021), alongside a 13.72% share of national seafood exports (Government of India (C), 2021). Complementing these sectors, Kerala's industrial and manufacturing base—anchored by traditional industries such as coir and cashew, which employ 3 lakh workers, predominantly women—remains vital for rural livelihoods and export earnings (Government of Kerala (B), 2024). At the same time, emerging value-added industries in chemicals, rubber, electronics, and pharmaceuticals are contributing to the State's economic diversification and growth.

Electricity Generation and Consumption

Kerala's power generation primarily depends on four key sources: hydel, thermal, wind, and solar. Among these, hydel power remains the dominant contributor to the State's electricity production. The State's energy mix is distinct in that most locally generated power is hydropower-based, while thermal and other renewable sources account for only a small share. Owing to limited firm hydropower availability, Kerala relies extensively on long-term contracted power purchases from outside the state, mainly from coal-based generation, to meet its electricity demand. To ensure a reliable electricity supply throughout the year, the State maintains Power Purchase Agreements (PPAs) with central generating stations such as NTPC, as well as with thermal and nuclear plants located in other states, supplemented by bilateral agreements.

As of March 2025, Kerala's total power installed capacity stood at 4412.15 MW[2], of which 2284.42 MW (51.78%) was sourced from hydropower, followed by 1519.66 (34.44%) from solar, 71.53 MW (1.62%) from wind, and remaining 536.54 MW (12.16%) from thermal sources (Kerala State Electricity Board Limited (A), 2025).

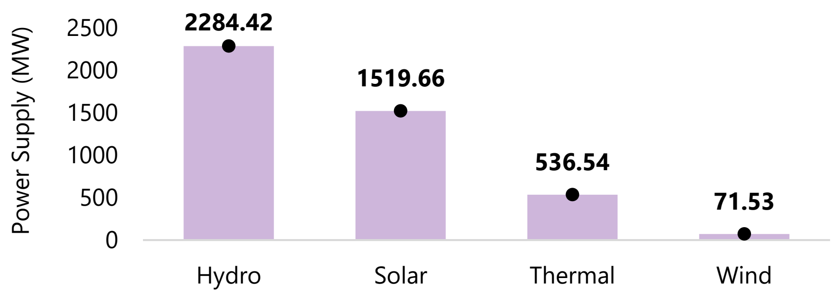


Figure 3: *Source-wise supply capacity mix (MW), inside Kerala, 2025*

Source: KSEB Annual Report 2024-2025

2 Including IPPs and captive renewable plant. The total has been corrected based on bifurcation provided in the Annual Report, resulting in 4412.15 MW, instead of 4412.14 MW as quoted in the report

Further, the electricity consumption in the State is predominantly by domestic consumers. In 2022, the domestic sector accounted for approximately 50.74% of the total electricity consumption (utility and non-utility) of 25,125.33 MU in the state, followed by the industrial (23.57%) and services (24.16%) sectors, which include commercial supply, public lighting and water works, and other miscellaneous supplies.

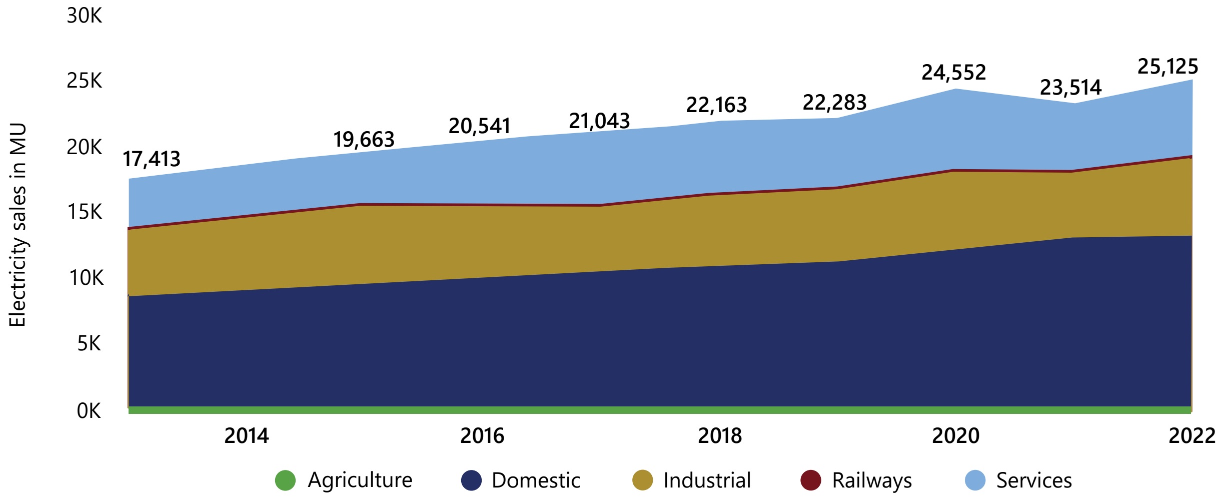


Figure 4: *Sector-wise electricity sales (utility and non-utility), in million units*

Source: Central Electricity Authority (CEA) and India Climate and Energy Dashboard (ICED)

In 2021-22, the state generated 10,932.08 MU of electricity, a figure overshadowed by its consumption (excluding transport), which soared to a staggering 25,125.33 MU (25.13 TWh). This significant disparity between generation and consumption highlights the State's increasing reliance on imported electricity. Kerala imports the majority of its power from neighbouring States and power markets. In the same year, the state sourced about 56.53% of its electricity requirement from coal-fired sources located in neighbouring states, revealing a concerning reliance on coal power plants (CPP). Consequently, this dependence on CPP contributes to indirect greenhouse gas emissions associated with meeting the state's electricity needs, and therefore, requires focused planning and policy efforts to decarbonise its electricity sector to achieve carbon neutrality in the State.

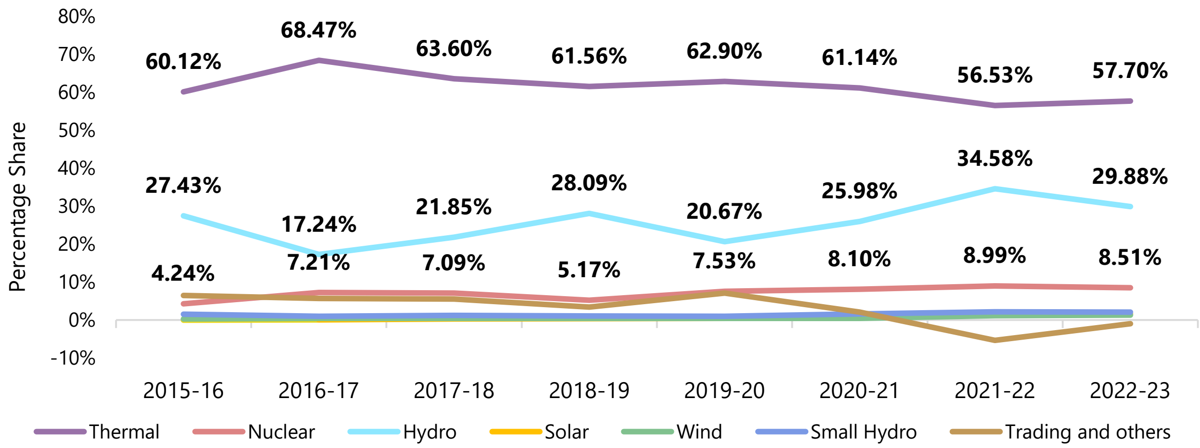


Figure 5: *Source wise share of electricity purchase in the state in between 2015-16 and 2022-23*

Source: India Climate and Energy Dashboard (ICED)
Note: The negative procurement through trading in FY2021-22 and FY2022-23 highlights the net export/sell of electricity

Current Emission Inventory

For over a decade, the State has experienced discernible changes in its emission landscape, as evidenced by shifts in both gross and net emissions. Despite the temporary respite provided by the pandemic, there was a notable decrease of around 24.82% in net emissions in the State over the period from 2005 to 2021, with net emission declining from 10.05 $MtCO_2e$ in 2005 to 7.55 $MtCO_2e$ in 2021 (See Figure 6).

The energy sector remained the predominant contributor to GHG emissions with total emissions of 17.36 $MtCO_2e$ (including aviation), accounting for about 78.28% of the State's gross emissions in 2021. This was followed by the waste sector which accounted for 8.66% – emitting 1.92 $MtCO_2e$, agriculture sector at 7.06% (1.56 $MtCO_2e$), and the IPPU sector at 5.94% (1.32 $MtCO_2e$) of the remaining gross emissions.

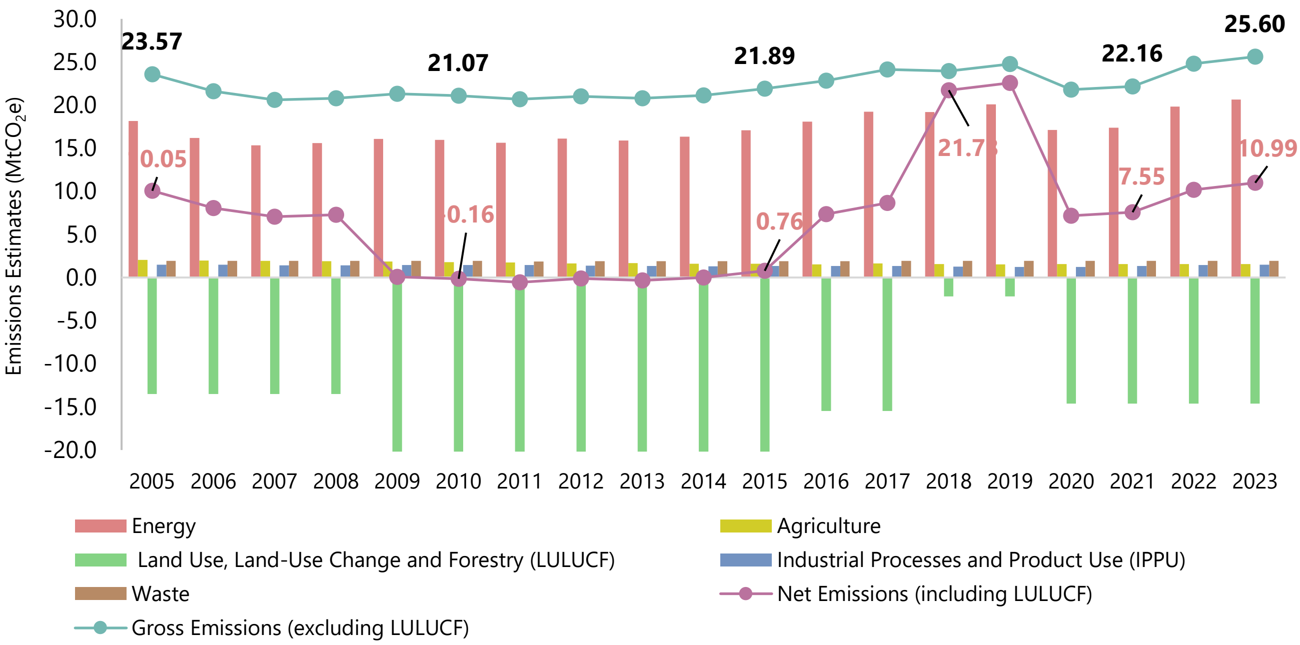


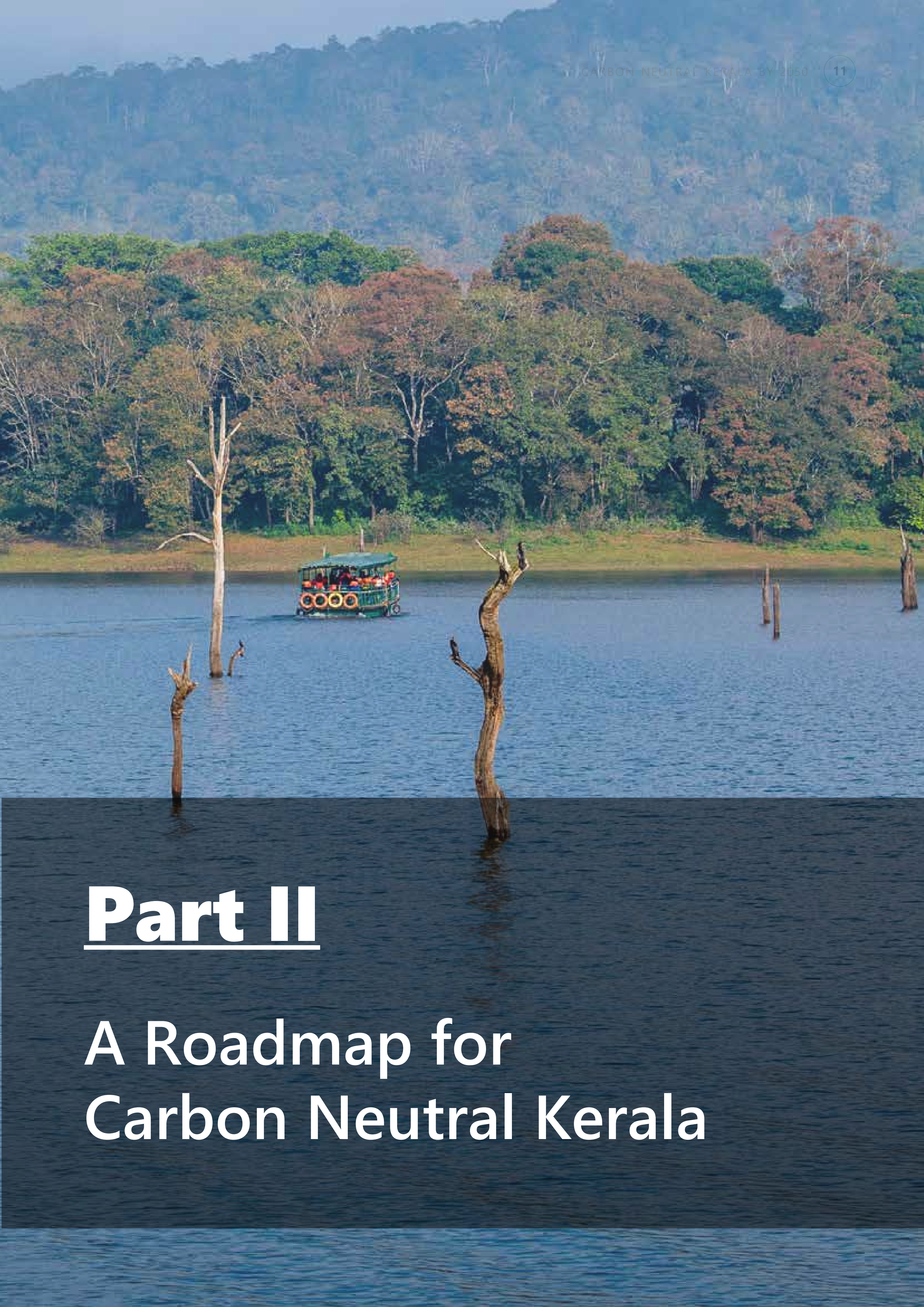
Figure 6: *GHG emissions from 2005 to 2023, in million tonnes of CO_2 equivalent*

Source: Kerala GHG Inventory Report Version 2 (2005 - 2023)

In the energy sector, transportation emerged as the major contributor, accounting for 63.18% of energy emissions in 2021, followed by the residential and industrial sectors. The chemical industry dominated emissions in the IPPU sector, which can be attributed to the ammonia production in the State. Within the agriculture sector, emissions from the livestock category (enteric fermentation and manure management) accounted for 71.20% followed by agriculture soil and rice cultivation. Notably, emissions from domestic wastewater significantly contributed (95.53%) to the total emissions from the waste sector, followed by solid waste and industrial wastewater.

The LULUCF sector as a whole acted as a net sink throughout 2005-2021. Within LULUCF sector, Forest land acted as a major sink. Between 2009 and 2015, an increase in the forest cover resulted in a noticeable increase in net sink. However, in 2018 and 2019, a major decline in sequestration was observed despite a nominal increase in forest cover of 0.26%. The net sink significantly increased post 2019, which can be attributed to steady growth of forest cover and carbon stock density.

Periyar National Park, Kerala



Part II

A Roadmap for Carbon Neutral Kerala

Carbon Neutral Kerala 2050 - Pathways and Roadmap

The carbon neutral pathway is in consonance with the Climate Change Mitigation plan of the State, incorporated in the Kerala State Action Plan on Climate Change (Government of Kerala (C), 2022). The GHG inventory combined with the CN50 Pathway provides a more comprehensive and strategic framework for effective mitigation measures within the State.

This section presents an outlook and projection of emissions and activities across both energy and non-energy sectors. Chapter 3 focuses on the energy sector, while Chapter 4 provides a detailed assessment of the non-energy sector.

The energy sector encompasses activities related to the production, transformation, and consumption of energy across key sub-sectors, including transport, public electricity generation, captive power plants, industry, commercial and residential use, and agriculture.

In contrast, the non-energy sector includes emissions from Industrial Processes and Product Use (IPPU), Agriculture, and Waste and carbon sequestration from LULUCF. IPPU covers emissions from non-combustion industrial processes such as cement production, chemical manufacturing, and product use. Agriculture includes emissions from livestock practices (enteric fermentation and manure management), agricultural soils, and rice cultivation while the waste sector accounts for emissions from solid waste and wastewater treatment. Additionally, carbon sequestration enhancement includes land-based (agroforestry and social forestry, and enhancing carbon stock density of existing forests) and blue carbon (restoration of mangrove cover) interventions.

Chapter 5, Aggregate Results & Key Insights, presents a roadmap for achieving carbon neutrality in the State, including sector-specific insights and policy recommendations.

Chapter 3

Energy Demand Outlook by 2050

Key Highlights

The State's energy demand, electricity consumption and emission outlook gives the following insights across the Business as Usual (BAU) and Carbon Neutral Kerala 2050 (CN50) scenario.

In the BAU scenario

- Kerala's energy demand is projected to **nearly double** from **372.34** PJ in 2021 to **648.04** PJ in 2050, influenced by population and economic tailwinds.
- As Kerala's EV Policy 2019, Industrial Policy 2023, and other policies promote deep electrification across energy sectors, the electricity share in the total primary energy supply would increase from **28.21**% in 2021 to **56.02**% in 2050.
- Further, **higher space cooling needs due to increasing temperature and heatwaves** – a major driver of electricity use in buildings – would also supplement the electricity growth. Both these factors would translate to a **more than three-fold** increase in electricity demand – from **25.84** TWh in 2021 to **92.54** TWh in 2050.
- Corresponding to this transition, energy related emissions in Kerala would peak in 2030 – at **21.90** $MtCO_2e$ from **17.35** $MtCO_2e$ in 2021, and subsequently decline to **20.53** $MtCO_2e$ by 2050 with higher EV share in vehicles.

In the CN50 scenario

- Kerala could abate **55.32**% (55.28%, excluding PEG) of these projected energy related emissions in 2050 through higher electrification, switching to cleaner fuel, and advancing energy efficiency across sectors. The residual emissions of **9.18** $MtCO_2e$ may remain, mostly due to ATF use in air transport, and residual fossil-fuel reliance in industries, buildings and transport.
- This economy-wide electrification would reduce energy demand – to **602.75** PJ in 2050. This deep electrification would likely result in an additional **33.67**% electricity demand growth – from **92.54** TWh in BAU 2050 to **123.70** TWh in 2050.
- Green Hydrogen would be a crucial driver of energy sectors' decarbonisation. Building upon the momentum of **155** TMT (equivalent to 155 kt) green hydrogen production by 2040 targeted under the draft hydrogen policy, the CN50 pathway projects green hydrogen production to grow to **200** kt by 2050.
- CNG is positioned as a critical bridging fuel for Kerala's energy sector, especially for both transport and cooking. This also compliments the higher utilisation of the Kochi CNG terminal. At present the terminal utilisation is in the range of 20-25%, which would eventually increase with higher gas consumption in the State.

Primer to the Projections

This chapter delves into the energy dynamics of Kerala, examining the composition of both primary and final energy sources across sectors. The primary objective is to understand the energy demand and supply in the state over the next twenty-five years, up to 2050, accounting for the policy nudges and their impact on potential future scenarios. This includes cases such as that of the state's new electric vehicle (EV) policy that incentivises EV adoption, and the Kerala Industrial Policy 2023 that supports increased manufacturing in electronic manufacturing, food processing and other sunrise sectors, while recognising electric vehicles as one of the priority segments for the State (Government of Kerala (D), 2023).

Based on the current energy use and future projections from this analysis, this chapter outlines the emission trajectory and mitigation potential across the IPCC sectors, namely, Energy, IPPU, Agriculture, Waste and LULUCF, along with their subsectors, in alignment with the Kerala GHG Inventory Report (Government of Kerala (D), 2024). This assessment is presented under two scenarios: **Business as Usual (BAU)** and **Carbon Neutral Kerala by 2050 (CN50)**, and are explained in the following sections.

Scenario Assumptions

The BAU scenario depicts energy and non-energy sector demand and supply growth in line with current policies and historical trajectories, wherever applicable. In this scenario, improvements in energy efficiency remain consistent with existing levels up to 2050. Similarly, limited potential for fuel switching persists, primarily through the electrification of road transport supported by initiatives like the Prime Minister's Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE) Scheme and the Kerala Electric Vehicle Policy 2019, while households and commercial establishments continue to use LPG and biomass for cooking.

The CN50 scenario, on the other hand, presents a more aggressive outlook aimed at focused decarbonisation in the state by 2050 while ensuring energy security. In this scenario, increased electrification of the transport fleet, adoption of clean cooking solutions, and improvements in energy efficiency is expected to significantly reduce fossil fuel demand and associated emissions. Table 2 depicts the detailed representation of scenario-specific assumptions.

Table 2: Scenario assumptions followed for BAU and CN50

Socioeconomic Assumptions	
Population	Projected increase from 33.40 million in 2011 to 35.49 million in 2021 and 36.95 million in 2036 (Government of India, November, 2019). Further increase to 40.23 million by 2050 analysed based on historical quinquennial growth (%) This assessment assumes complete urbanisation in 2050, in reference to the Economic Review 2024 that predicts 96.4% urbanisation in Kerala by 2036 (Government of Kerala (A), 2025).
GSDP	Increase from ₹5.71 lakh crore (Provisional Estimate) in 2021-22 to ₹6.85 lakh crore (Provisional Estimate) in 2024-25, reflecting a 6.21% growth rate (inflation-adjusted, pre-COVID level) (Reserve Bank of India, 2025). The same YoY growth rate of 6.21% is assumed to continue till 2050.

Sectoral GVA	The service sector predominantly drives Kerala's economy, with a substantial 63.8% share of GVA in 2022-23 (Government of India (D), 2025).			
Sectoral Assumptions				
Sector	**Disaggregation**	**Driver**	**Scenario-BAU**	**Scenario-CN50 (over and above BAU)**
Agriculture	Irrigation, agro-machinery (tractors and tillers)	Agricultural water consumption, crop production, fuel demand, GSDP	Phase out of diesel pumps by 2030.	100% electrification of pumpsets by 2030, and of agro-machinery by 2050.
Buildings	Cooking	GSDP and demography change → change in appliance ownership.	Presently, 88% cooking demand met through LPG, followed by biomass (10%) and electricity (2%). BAU 2050 considers the same share of biomass and electricity till 2050. LPG will reach 14% and PNG 74% in 2050.	50% of cooking demand will be met through electric cookstoves, followed by PNG (45%) and LPG (5%) by 2050.
	Residential and commercial buildings, public lighting, miscellaneous services	GSDP and demography change → change in electricity consumption patterns	No additional or enhanced energy efficiency programmes beyond the existing initiatives are considered	Higher energy efficient appliance penetration in building sectors.
Transport	Air, rail, road, water shipping	Passenger kilometre, tonnage-kilometre, vehicle ownership, passenger load.	Current trends of EV penetration.	Higher EV penetration compared to BAU, especially for the 4W and HGV vehicle category.

Sector	Disaggregation	Driver	Scenario-BAU	Scenario-CN50 (over and above BAU)
Industry	Petrochemical, chemical, food processing, rubber, cement, paper products, etc.	Fuel Consumption, GVA	No additional interventions for decarbonisation and fuel switching.	Replacement of fossil fuel-based heating systems by electric heating equipment and GH_2-based plasma generators. Replacing 100% natural gas used in fertilizer production with green hydrogen.
Green Hydrogen (GH_2)*	Heavy-duty transport (buses, HGVs and shipping), petrochemicals, and chemical industries	Target as per Draft Kerala GH_2 Policy 2025	No green hydrogen production	Production of GH_2 of 155 kt in 2040 and 200 kt by 2050

*Assumption regarding production of green hydrogen; application scenarios are covered in the other sectors.

The Energy System Model

The Integrated MARKAL-EFOM System (TIMES) (Loulou, Goldstein, & Noble, October 2004) has been used to develop long-term energy scenarios for the State. The energy model has a bottom-up, linear programming structure with representation of all technologies to represent energy supply, transformation of energy commodities and demands. Furthermore, this energy model is also supported by a database of future technologies which characterises technologies that could potentially be deployed in Kerala in future years. The model is run up to the target year 2050 – with the entire-time horizon divided into 5-year intervals, to meet the energy service demands while minimising the total discounted system cost under various policy constraints.

This model is divided into 6 sectors - agriculture, fisheries, industry, power, buildings, and transport. In addition, Python for Power System Analysis (PyPSA) is utilised for a high-resolution modelling of the power sector operations to meet electricity demands across sectors. The energy service demands for all sectors are projected till 2050 in line with the population and economic growth assumptions. Results of the power sector are provided in Part III of this report, while the subsequent sections of Part II address the remaining energy sectors.

For the purpose of this analysis, TIMES has been tailored to Kerala's unique energy profile and carbon neutrality goals using localised data on energy demand, supply options, existing policy mandates, and relevant economic factors. A detailed modelling framework is in Annexure *4*.

Box Item 1: Brief Description of the TIMES Energy System Model

The TIMES model generator was developed as part of the Energy Technology Systems Analysis Program (IEA-ETSAP), an international community which uses long-term energy scenarios to conduct in-depth energy and environmental analyses. It is a technology-rich, bottom-up model generator, which uses a linear-programming framework to produce a least-cost energy system, optimised according to a number of user constraints, over medium to long-term time horizons. The TIMES model generator combines two different, but complementary, systematic approaches to modelling energy: a technical engineering approach and an economic approach. Briefly, TIMES is used for "the exploration of possible energy futures based on contrasted scenarios."

Models exogenously used as an input to the TIMES Energy System model: The TIMES model generator explores pathways for a possible energy future. However, certain assumptions drive the output of TIMES scenarios from models exogenous to TIMES. A few of them are listed below:

Appliance Stock Model: The appliance stock model is used wherever residential buildings consume electricity to run the appliances. The model calculates appliance growth of various energy-intensive and non-intensive devices over the past years. Thus, the output of this model is used as an input to TIMES, which undertakes the decision to invest in the most cost-optimum/environment friendly appliance. This has been elaborated further in the sub-section on road transport.

Vehicle Stock Model: The model projects vehicle category-wise vehicle stock per capita. The model used the Gompertz function.[3] This depends upon the saturation effect — the tendency for demand to slow down as it approaches an upper limit. This is relevant in terms of developing economies, where the propensity to consume plateaus once economies tend to develop. Further, a stock replacement model is used in tandem to replace the vehicle stock based on lifespan.

Energy Use in Irrigation: The demand for energy use in agriculture is based on the amount of water that needs to be pumped or the extent of hours that a tractor needs to be run for land preparation. The crop-wise irrigated area (ha), along with average yield of irrigated area (kg/ha) and irrigated water productivity (kg/m^3) have been used to estimate annual crop-wise water requirement.

Some of the other end-use demand sectors, including Industry and services, are modelled exogenously to estimate the energy demand in future years. Further, in addition to TIMES, a detailed and granular electricity capacity expansion and dispatch model is built using Python for Power System Analysis (PyPSA) to estimate the electricity supply mix of Kerala by 2050. This has been detailed in Chapter 6 (Part III).

Model Uncertainties

Energy models are inherently subject to uncertainties arising from various parameters such as GSDP growth, technological advancements, and policy shifts. These uncertainties stem from the complex and dynamic nature of the economies, advancement

3 Gompertz Growth model is a function that describes growth as being slow at the start and the end of a given period of time. Originally used in biology, it is being increasingly applied for economic and non-economic predictions, including that of vehicle ownership growth. Read Torok, Adam. "Prediction of Vehicle Ownership Growth using Gompertz Model, Case Study of Hungary." CzOTO 2022, Volume 4, Issue 1, PP. 164-169.

in technology, and shifts in policy and regulatory environments – making long-term energy demand forecasts challenging. GSDP projections, for instance, could vary based on the shift in sectoral priorities and the regulatory landscape of the State. Similarly, assumptions about the adoption rate of new technologies could introduce significant variability into model outcomes for energy consumption and emissions.

To ensure relevance and robustness, the model used for this analysis, while deterministic, incorporates policy changes within the state to ensure relevance. Additionally, wherever possible, sensitivities have been tested, particularly in the power sector, to assess the impact of key uncertainties on outcomes.

The modelling results from this analysis are not meant to be used as forecasts, but rather to serve as directions to inform policy decisions towards enabling the State achieve carbon neutrality. With changes in state policies and technology enhancements, these plans would be revised regularly to keep them relevant.

Current Energy Demand and Future Projections under BAU and CN50 scenarios

The TIMES model developed for this analysis uses projected energy service demands across Energy sectors. Further, emissions are estimated at the level of sectors, sub-sectors and categories based on the GHG Inventory Report (Government of Kerala (D), 2024).

The energy sector includes emissions from a range of activities related to the production, combustion, and consumption of energy.

The major sub-sectors for emission estimates within the energy sector are transport, public electricity generation, captive power plants, industries, commercial and residential energy use, and agriculture. These sub-sectors collectively address both direct fuel combustion and electricity use, forming a central focus for greenhouse gas (GHG) mitigation due to their significant emissions contributions.

Energy Sector

The emissions from the energy sector accounts for 78.29% of the total GHG emissions in the State[4]. Within the energy sector, the major emitters are transport, buildings, and industries (including captive power), accounting for 63.18%, 21.58% and 14.49% of total energy emissions, respectively. Therefore, while the plan provides a detailed coverage of all energy subsectors, the recommendations proposed in this report places special emphasis on transport, buildings and industries. The details are provided below.

4 The Kerala GHG Inventory Report Version 2 (2005-2023) estimates energy emissions in 2021 to be 17.36 $MtCO_2e$, which is 78.34% of 22.16 $MtCO_2e$ of total gross emissions. This report uses revised estimates, which account for petcoke in industrial energy emissions. Fuel allocation across the agriculture, residential, and commercial categories has also been updated based on the CRISIL Report.

1. Transport

The transport sub-sector comprises road transport, railways, airways and water-based transport. In 2021, the subsector contributed 10.97 $MtCO_2e$ of emissions. Road transport was responsible for 9.66 $MtCO_2e$ (88.09%), followed by air transport (7.88%; 0.86 $MtCO_2e$), and fisheries (3.31%; ~0.36 $MtCO_2e$). Contribution of water transport and railways in total sub-sectoral emissions were 0.04 $MtCO_2e$ (0.36%) each.

1.1 Road Transport

Road transport in Kerala is dominated by 2-wheelers (2W), constituting 56.36% of the total vehicles registered in the State by 2021, followed by 4-wheelers (4W) at 19.54% (MoRTH, 2021). This dominance is brought about by increased income levels in the State and consequently higher spending capacity – resulting in an increasing trend in individual vehicle ownerships. Nevertheless, public transport – including buses and 3 wheelers (3W) – remains an integral part of Kerala's transport system and holds significant importance for the sectoral decarbonisation.

Methodology

A vehicle stock model considering two broad categories of passenger vehicles (including 2W, 3W, 4W, and buses) and freight vehicles (including trucks and light goods vehicles) is developed to project the total vehicle ownership per capita. Further, a stock replacement model is used to project segment wise vehicle stock in the future. This projection is based on existing stock, ownership over time and vehicle saturation levels – adjusted in coherence with India's current vehicle saturation growth rate.[5] In each vehicle segment, the lifetime of vehicles is assumed in line with industry benchmarks to estimate the on-road active stock. Other key assumptions include operating parameters such as annual vehicle kilometres, mileage, and efficiency improvements.

Total registrations by vehicle type from MoRTH is used alongside data of new vehicle registration from the VAHAN dashboard on need basis (Table 3). The varying levels of EV adoption under the BAU and CN50 scenarios are given in Table 4, and the total electric vehicle stock for both scenarios is provided in Table 5.

Table 3: Total Registrations by Type in Kerala, as on 2021

Year	2W	3W	4W	Bus	HGV	Others
2021	96,74,086	7,07,577	33,54,693	1,35,791	5,60,549	27,32,983
% Share	56.36%	4.12%	19.54%	0.79%	3.27%	15.92%

Source: Data as per MoRTH 2020-21 (Government of India (C), 2025)

Table 4: Actual and Projected Electric Vehicle Adoption Rates (%) in New Sales, BAU and CN50 Scenarios

Scenario	Year	2W	3W	4W	BUS	LGVs	HGVs
Actual	2021	1.14%	9.07%	0.71%	0.00%	0.38%	0.00%
	2025	14.04%	20.43%	10.37%	0.67%	2.50%	0.00%

5 The rate of four-wheeler ownership in India is still far less than in the western countries like the United States (349 cars per thousand capita), Japan (479 cars per thousand capita), and the United Kingdom (470 cars per thousand capita) – offering a higher scope for increase in vehicle ownership. (The Energy and Resources Institute, 2024)

Scenario	Year	2W	3W	4W	BUS	LGVs	HGVs
BAU	2030	50.00%	50.00%	10.00%	20.00%	10.00%	0.00%
	2040	100.00%	100.00%	25.00%	50.00%	25.00%	0.00%
	2050	100.00%	100.00%	50.00%	75.00%	50.00%	0.00%
CN50	2030	75.00%	75.00%	25.00%	25.00%	25.00%	5.00%
	2040	100.00%	100.00%	75.00%	75.00%	60.00%	30.00%
	2050	100.00%	100.00%	100.00%	90.00%	100.00%	65.00%

Note: The years represent the calendar year.

Table 5: Projected Electric Vehicle Stock, by Vehicle Type across Scenarios

Scenario	Year	2W	3W	4W	BUS	LGV	HGV
BAU	2030	12,57,770	93,432	1,33,720	1,853	17,734	0
	2040	59,18,611	4,70,235	6,77,679	14,043	95,224	0
	2050	99,33,041	8,42,355	18,25,088	38,310	2,11,512	0
CN50	2030	16,70,876	1,23,916	2,45,251	2,146	20,917	805
	2040	70,16,294	5,54,467	18,75,798	19,893	2,04,383	13,854
	2050	1,00,93,358	8,55,351	44,09,447	51,290	5,28,146	49,575

To assess electricity consumption and emissions resulting from electric vehicles replacing ICE vehicles, assumptions regarding battery size (in kWh) and battery range (in km) are made for each vehicle category and are given in Table 6.

Table 6: Vehicle characteristics assumptions by Vehicle Type

Characteristics	2W	3W	4W	BUS	LGV	HGV
Battery size (kWh)	2-3	5-7	28-60	125-350	60-150	200-600
Battery range (km)	80-100	90-140	250-400	250-350	150-300	200-800
Payback over ICE vehicle (years)	2 – 3	2 – 4	5 – 6	7 – 8	4-5	6-7
Emission abatement w.r.t. Fossil fuel vehicle (tCO2/vehicle/year)*	0.5-0.8	1.5-2.0	2.8-3.5	80-100	9.1-10.5	115-135

*If charged with renewable sources

Key Insights

This section provides projected results on vehicle ownership per capita, transport demand in terms of billion passenger kilometres (BPKM)[6] and billion tonne kilometres (BTKM)[7], and the resulting changes in fuel and electricity consumption from 2021 to 2050.

Trends in Vehicle Ownership

Kerala has one of the highest densities of private vehicle ownership. Rising per capita income, and an increasing propensity for household consumption in the State are expected to further increase adoption of private vehicles – boosting growth of private 2W and 4W compared to public transport such as buses and 3Ws (autos, rickshaws etc). As per vehicle registration data from Vahan Dashboard, in 2021, the State registered 264 two-wheelers (2W) and 96 four-wheelers (4W) per 1000 capita – both of which are further expected to grow to 300 two-wheelers (2W) per 1000 capita and 157 four-wheelers (4W) per 1000 capita by 2050. In terms of public mobility, the per capita availability of public transit is projected to remain fairly constant – increasing only marginally from 21 3Ws/LMVPs and 1 bus per 1000 capita in 2021 to 25 3Ws and 2 buses per 1000 capita in 2050 *(Figure 7)*.

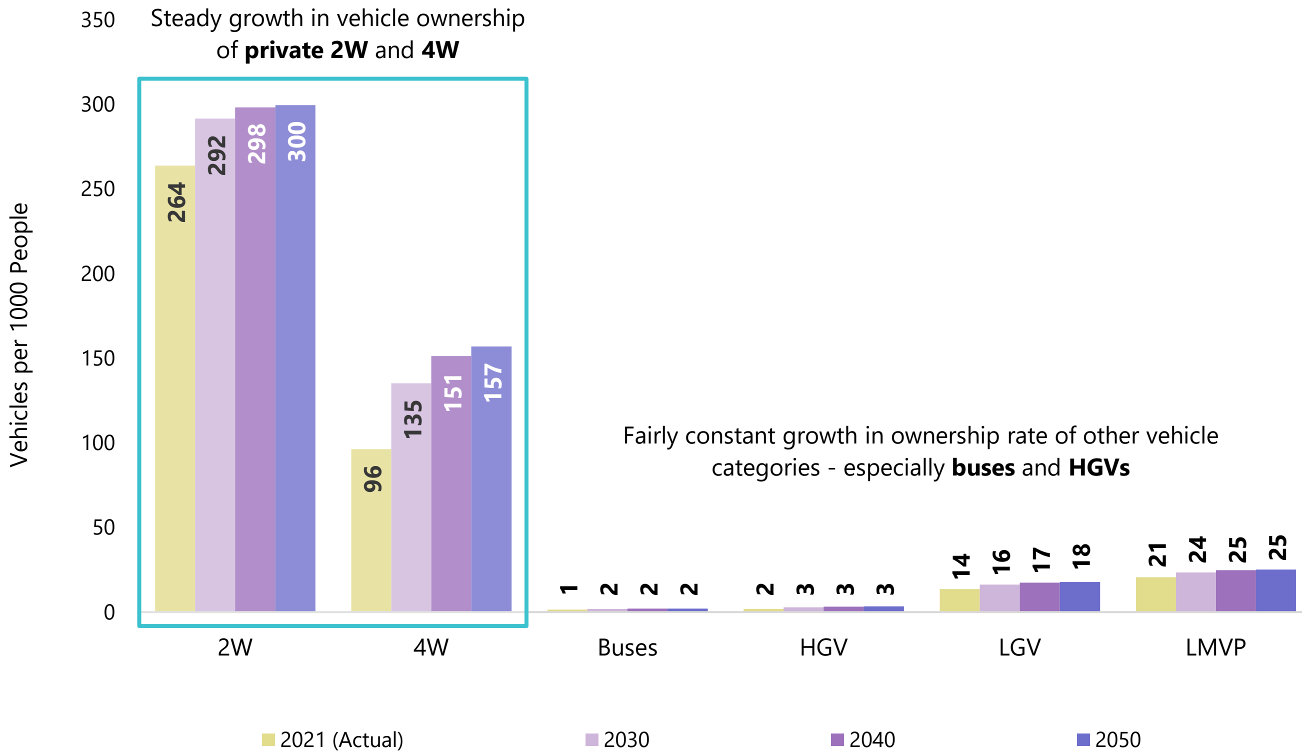


Figure 7: *Vehicle ownership in Kerala between 2021 and 2050, by vehicle type, per 1000 people*

Note: Vehicle ownership projections are assumed to be the same for BAU & CN50 scenarios

6 Indicates total distance traveled by all passengers on a specific mode of travel. It is calculated by multiplying the number of passengers by the distance they traveled.

7 BTKM refers to a tonne of goods transported multiplied by distance travelled in kilometers.

Trends in Transport Demand

Similarly, the total transport demand for passenger vehicles – covering 2W, 3W, 4W, and buses, and measured in terms of billion passenger kilometres (BPKM) – is projected to increase by 48.31% from a cumulative 325 BPKM in 2021 to 482 BPKM in 2050. The total freight demand – covering Light Goods Vehicles (LGVs) and Heavy Goods Vehicles (HGVs), and measured in terms of billion tonnes kilometre (BTKM) – is expected to increase from 42 to 65 BTKM during the same period *(Figure 8).*

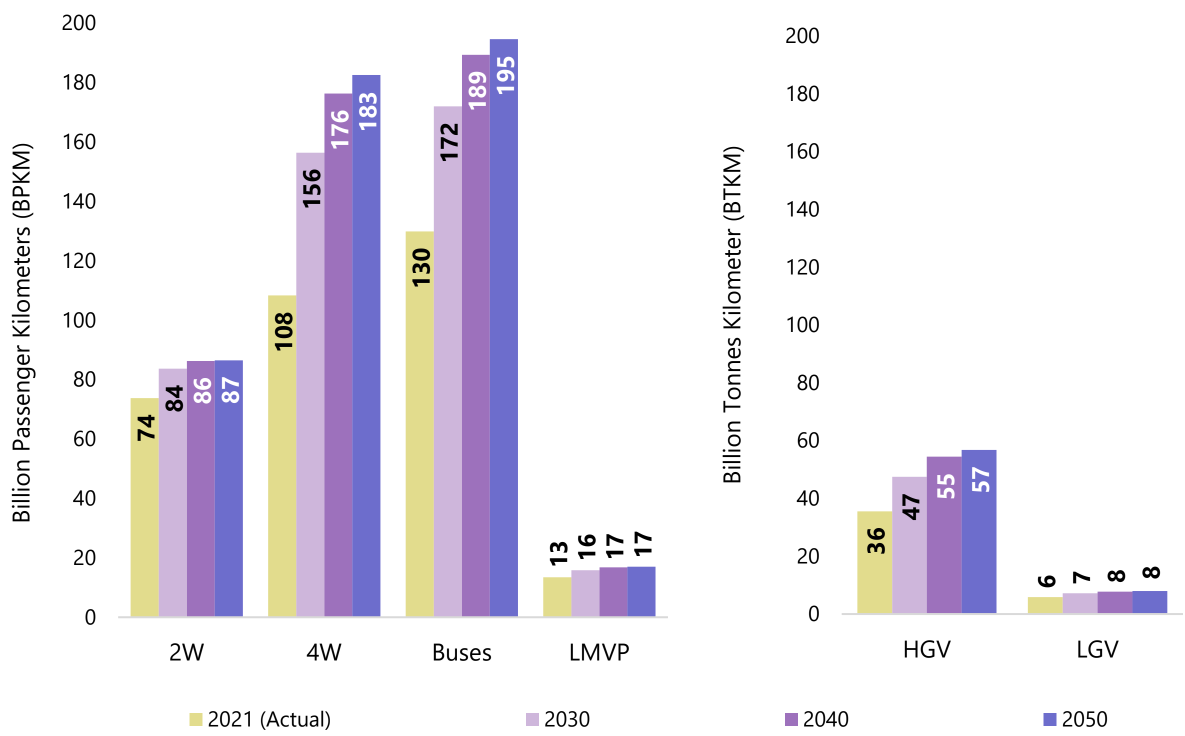


Figure 8: *Transport demand in Kerala between 2021 and 2050, by vehicle type, in BPKM and BTKM*

Private passenger mobility increases aggressively by 2030, while saturating thereafter – particularly in the two-wheeler segment with saturating vehicle ownership. *Transport service demand in billion tons kilometre (BTKM) for light and heavy goods vehicle

Trends in Energy Demand and Emissions in Road Transport

In 2021, energy demand by the road transport fleet stood at 169.39 PJ, driven primarily by diesel and gasoline consumption. Diesel and gasoline use is expected to continue growing, pushing energy demand to a peak of 189.47 PJ by 2030**,** before declining to 145.50 PJ by 2050 on account of gradual replacement of diesel and gasoline with more energy efficient electricity – supported with incentives under the Kerala Electric Vehicle Policy 2019. This would decline the road transport emissions from 9.66 $MtCO_2e$ in 2021 to 7.66 $MtCO_2e$ in BAU 2050.

In the CN50 scenario, electricity emerges as the dominant energy source for transport. A 30.31% reduction in energy demand could be achieved – from 145.50 PJ in the BAU 2050 scenario to 101.40 PJ, through accelerated electrification particularly in the 4W, bus, and HGV segments. Installation of 13,000 charging stations and development of other allied infrastructure would support this electrification. Correspondingly, emissions would decline to 0.98 $MtCO_2e$ (87.21% reduction from BAU 2050 levels). Residual emissions would remain on account of continued diesel and gasoline consumption in buses and HGVs *[Figure 9 (a)].*

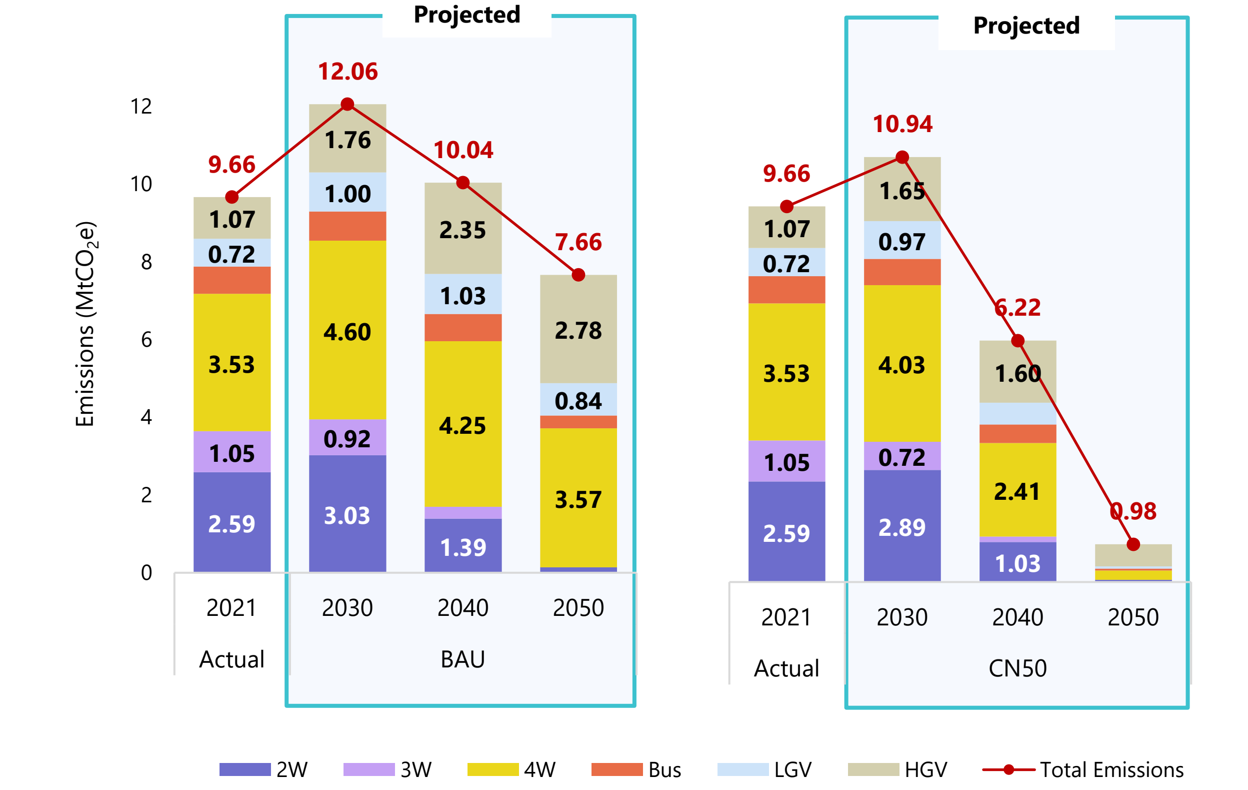


Figure 9 (a): *Vehicle category wise emissions in road transport in Kerala, in $MtCO_2e$*

Note: While 100% electrification in new sales of 4Ws, 90% for buses and 65% for HGVs by 2050 would slowly reflect in vehicle stock. As a result, residual emissions would remain in CN50 – due to continued diesel and gasoline consumption – particularly in these vehicle categories.

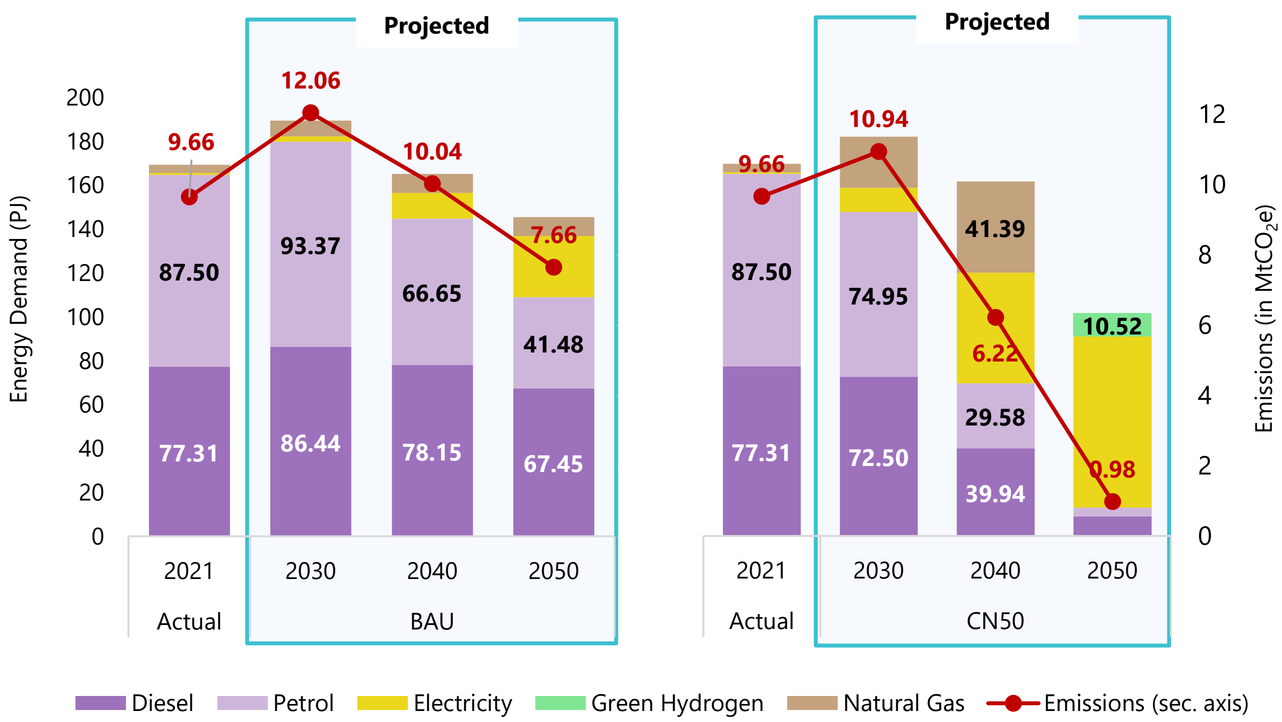


Figure 9 (b): *Energy demand and resultant emissions in road transport in Kerala, by fuel type, across scenarios, in PJ and $MtCO_2e$ respectively*

Note: Diesel and gasoline use remains predominant in the BAU scenario. Higher electrification, green hydrogen usage and reduced fossil fuel dependence is the key to decarbonise road transport.

Fuel-share wise, diesel and gasoline demand are projected to fall sharply from 67.45 PJ and 41.48 PJ in the BAU 2050 scenario, to 9.00 PJ and 4.03 PJ, respectively, under the CN50 scenario. *[Figure 9 (b)]* Gasoline use remains mainly to meet the needs of remaining ICE vehicles in vehicle stock, while a limited amount of diesel continues to be required for HGVs. CNG is positioned as a critical bridging fuel for Kerala's transportation sector, particularly for three-wheelers (3W), four-wheelers (4W), and buses, till 2040. Additionally, in CN50, the remaining 35% of HGVs in new sales and 10% of non-EV new sales in bus segments are expected to transition to Green Hydrogen-based Internal Combustion Engines (GH_2-ICE) or Green Hydrogen based Fuel Cell EVs (GH_2-FCEV).

Trends in Electricity Requirement

This change in energy mix also reflects the trends in electricity consumption *(Figure 10)* in road transport – which is expected to increase from 0.22 TWh in 2021 to 7.78 TWh in 2050 due to current policy push and market development. With higher EV adoption in the CN50 scenario, the electricity consumption could potentially triple to 21.62 TWh in 2050.

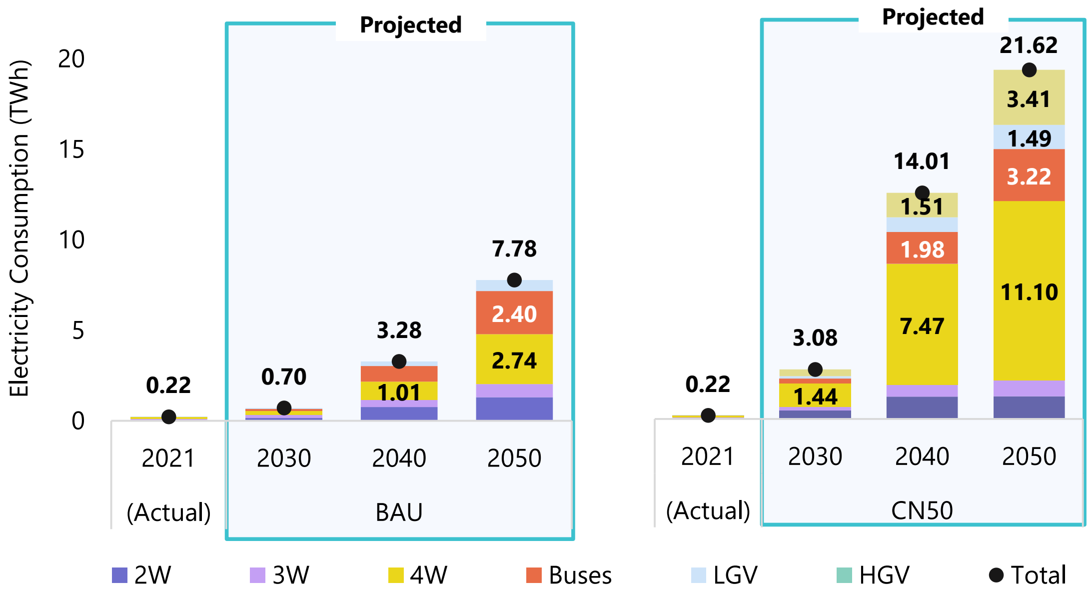


Figure 10: *Electricity Consumption in road transport in Kerala, by vehicle type, across scenarios, in TWh*

Vehicle-type wise, electrification of 4W, buses and HGVs are paramount under the CN50 scenario.

Box Item 2: Decarbonising Kerala's road transport hinges on promotion of public transport, supported by timely development of allied infrastructure.

Kerala's shift to electric mobility for its heavy vehicle fleet, especially KSRTC buses, requires robust charging infrastructure. The draft Kerala EV Policy 2025 targets 2,000 EV charging stations statewide, with KSRTC planning depot-level chargers across all 73 depots and 20 operating centres — beginning with Munnar, Vithura, and Sultan Bathery. The policy further mandates charging points every 25 km along major highways to support long-distance operations. Financially, KSEBL is facilitating an 80% subsidy on upstream infrastructure costs under the PM E-DRIVE scheme, which also earmarks around 1,800 dedicated stations for e-buses nationally. Given the projected fleet of 52,910 electric buses and 50,749 HGVs — all requiring high-capacity DC fast chargers of 60–250 kW — an estimated 13,000 charging stations will be needed in Kerala by 2050.

Key Interventions to Decarbonise Road Transport in CN50

As much as 87.21% of projected road transport emissions could be abated by 2050 through,

- **Prioritising Electrification of 2Ws and 3Ws in Near Term:** Electric vehicle adoption in new sales has increased significantly in recent years. By further targeting 75% electrification in new sales of 2Ws and 3Ws by 2030, subsequently achieving 100% by 2040, emissions from road transport could be significantly abated. In vehicle terms, this would translate to a cumulative adoption of approximately 1.06 crore e-2Ws and 8.98 lakh e-3Ws by 2050, corresponding to an active on-road electric stock of about 1.01 crore e-2Ws and 8.55 lakh e-3Ws after accounting for vehicle retirement cycles.[8]
- **Promotion of Public Transport Transition in Long Term:** In 2021, the EV registrations in total new registrations for 4Ws was low, at 0.71%. No new electric bus was registered in that year in Kerala. Against this, near complete electrification in the new registrations for 4W and buses could be targeted by 2050. This translates to an addition of 45.60 lakh electric 4Ws and 52,910 intra/inter State electric buses to replace existing ICE. The priority could be given to intra state buses and government owned commercial 4Ws.
- **Scaling up of Charging Infrastructure:** To support fleet electrification, the electricity distribution infrastructure would have to be augmented – focusing first on urban areas where 2W/3W adoption is expected to be highest. This could be supplemented with an increase in capital investment in public charging points at bus bays, fuel stations, parking lots, and malls. At least ~13,000 new charging stations across the State should be targeted by 2050.
- **Freight Transport Electrification and Modal Shift:** Furthermore, Kerala could encourage a modal shift from road to rail and inland waterways for freight transport to reduce fuel demand. Additionally, adoption of electric and hydrogen-powered freight vehicles could be incentivised.

6.68 $MtCO_2e$ of Decarbonisation Potential by 2050	**Stakeholders***:* Individual Users, State Transport Department (policies/ subsidies), RTOs (monitoring and progress), Local Businesses (repair and allied services), Industry (tech availability and infrastructure), Financiers (investment and capital)

1.2 Air Transport

Air transport accounts for the second highest emissions at sub-sectoral level, accounting for 7.88% (0.86 $MtCO_2e$) of transport related emissions. Kerala's aviation industry has emerged as one of the fastest growing sectors in recent years. With an increasing demand for international travel and cargo transit – supported by four operational international airports (Cochin International Airport, Kannur International Airport, Thiruvananthapuram International Airport, and Kozhikode International Airport), emissions from air transport in Kerala are expected to grow.

8 The numbers specified represent total registrations/adoptions to be made by 2050. Assuming vehicle wise useful lifecycle, total electric vehicle stock for these categories would be slightly lower, as provided in Table 5

This section on air transport has been divided in two main segments namely - air passenger and air freight. This section provides a detailed breakdown of projected growth in air passenger and cargo demand in the State up to 2050, with resulting energy and emission trends.

1.2.1 Air Passenger Segment

Air passenger traffic in Kerala comprises both domestic and international movement. In 2021, about 59.08% of all airport movement was domestic, and 50.36% happened through the Cochin International Airport alone. (Table 7).

Table 7: Passenger flight statistics of Kerala, in 2020-21

Airport	Domestic		International	
	Annual Movement (in numbers)	Annual Air Passenger Traffic (inLakh)	Annual Movement (in numbers)	Annual Air Passenger Traffic (in Lakh)
Cochin International Airport	16,803	15.48	8,109	9.09
Kannur International Airport	3,985	1.84	2,321	2.96
Thiruvananthapuram International Airport	5,111	4.76	4,202	4.58
Kozhikode International Airport	3,327	1.89	5,611	7.12

Source: Data from Annexure II: Airport Movement and Annexure III: Passenger from Airport Authority of India (AAI) (Airport Authority of India , 2021)

Methodology

In the absence of breakup data on fuel consumption for passenger and freight air traffic, total flying demand is estimated based on current domestic and international departures from the State. This approach allows differentiation of Aviation Turbine Fuel (ATF) demand for both passenger and freight segments.

First, the fuel requirement for onward departures from all airports in Kerala is calculated based on an average daily passenger flight traffic. Operational parameters like passenger miles per gallon (pmpg), air distance, seating capacity, aircraft types are used.

The passenger movement in BPKM and the total fuel consumption (million litres) are calculated. Thereafter, the total ATF consumption from the passenger demand is deducted to arrive at freight fuel consumption, this is to estimate the fuel consumption shares amongst both the air traffic modes.

To calculate the total future fuel demand, growth in the fuel consumption is estimated for the coming years. A marginally higher growth in international transit as compared to domestic demand is assumed, based on recent years growth in international aviation.

> **Considering that the air transport falls outside the State's jurisdiction, and that its decarbonisation is subject to development of viable alternatives of aviation fuel, this analysis details the BAU scenario alone. While no intervention is proposed under the CN50 pathways, as the technology develops and the proof of scale is proved for Sustainable Aviation Fuel (SAF), these emissions could be subsequently captured.**

Key Insights

The air passenger movement in and out of Kerala is presented in Table 8. The total aviation fuel demand is expected to grow nearly six-fold, from 117.60 kt in 2021 to 692.56 kt in 2050. This increase in ATF consumption will have a remarkably high implication on the residual GHG emissions from aviation, and therefore, on the overall transport sector. Fuel substitution in air transport as an intervention is yet being explored. As the Sustainable Aviation Fuel (SAF) technology evolves, and application becomes technically and economically viable, air transport related emissions can be subsequently captured.

Table 8: Projected ATF consumption and Air passenger movement in Kerala

Scenario	Year	ATF Consumption (TMT)	Passenger Movement (BPKM)	
			Domestic*	International*
Actual	2021	117.60	1.75	4.27
Projected - BAU	2030	406.34	6.47	15.77
	2040	554.23	9.71	23.69
	2050	692.56	13.38	32.63

Source: ATF consumption, Indian Petroleum & Natural Gas Statistics 2020-21

** Computed based on annual number of flights, occupancy rate, with 80% duty cycle, and trip length (in km)

1.2.2 Air Freight Segment

Kerala's air cargo sector is evolving into a dynamic, tiered network, with each of its four international airports serving a specialised role. Table 9 outlines the performance and strategic functions of each airport, detailing the cargo volumes handled during the 2022-23 fiscal year.

Table 9: An Overview of Kerala's Air Cargo Sector (2022-23)

Airport	2022–23 Cargo Handled	Key Role / Specialisation	Infrastructure & Future Capacity
Cochin International Airport (CIAL)	72,818 MT (↑22% YoY)	State's dominant freight gateway	Established hub with strong year-on-year growth

Airport	2022–23 Cargo Handled	Key Role / Specialisation	Infrastructure & Future Capacity
Trivandrum International Airport (TRV)	16,722 MT (↑8% YoY)	Pharma & perishables; leveraging southern location for Gulf & Europe markets	Strategic second pillar of Kerala's air-cargo sector. TRV is also ISO-certified for Quality, Environment, Occupational Health & Safety and Energy Management.
Kozhikode International Airport (CCJ)	14,523 MT (↑10% YoY)	Farm-to-Gulf exports (fruits, seafood, spices); Gulf-origin unaccompanied baggage & commercial imports	ISO-certified cargo complex for its quality management systems.
Kannur International Airport (KIAL)	~3160 MT (↑12% YoY)	Emerging cargo hub; targets Malabar–Kodagu–Mysore catchment	Interim facility: 18,000 MT p.a.; Upcoming International Cargo Complex: 60,000 MT p.a. (~3.5× expansion capacity)
Statewide Total	1.07 lakh MT	Integrated logistics corridor	Potential to double throughput within the decade through Kannur & Calicut expansions
Source: ECONOMIC REVIEW 2023, State Planning Board, Thiruvanan-thapuram, Kerala, India January 2024			

Methodology

The estimation of air freight load for the present and future years was based on the correlation between fuel consumption in conjunction with the volume of air cargo trade in BTKM. The residual fuel consumption is estimated by deducing passenger fuel consumption from total fuel consumption and then benchmarking fuel consumption per tonne-kilometre of cargo hauled.

Key Insights

As of 2023, the combined air cargo handled by Kochi, Kozhikode, Thiruvananthapuram and Kannur stood at ~0.11 Million Metric Tonnes Per Annum (MMTPA). This is estimated based on future cargo handling capacity and futuristic growth, in which cargo handling capacity could grow from 0.09 MMTPA in 2021 to 0.29 MMTPA in 2050. Based on the analysis, air cargo contributed 35.06% of the total ATF consumption in 2021, a pattern which is expected to continue by 2050. As a result, fuel consumption by air cargo is projected to increase from 63.5 kt in 2021 to 373.92 kt in 2050.

Aggregated Energy Demand and Emissions for Air Transport

Energy demand in air transport is expected to increase from 10.54 PJ in 2021 to 57.90 PJ in 2050, driven by economic growth, rising income levels, and subsequent increase in air traffic. The share of the passenger segment in total energy demand against that of the freight segment is expected to remain in the range of 71-73% in both 2021 and 2050. Emissions are expected to grow from 0.86 $MtCO_2e$ in 2021 to 4.10 $MtCO_2e$ in 2050 due to increase in ATF consumption, corresponding to increase in energy demand for passenger and freight travel *(Figure 11)*.

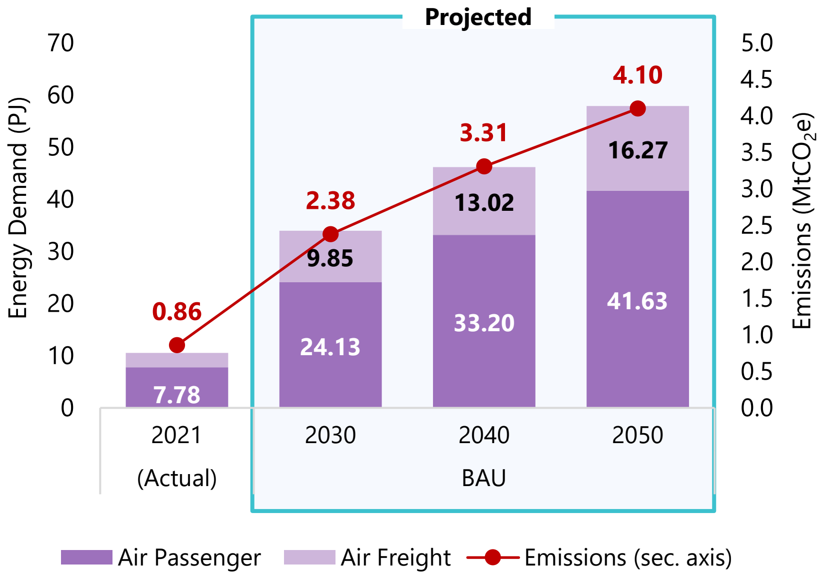


Figure 11: *Energy demand and resulting emissions in air passenger segment in Kerala, actuals in 2021 and projections till 2050 under BAU, in PJ and $MtCO_2e$ respectively*

Note: Emissions are assumed to remain the same in CN50 as well.

Key Interventions to Decarbonise Air Transport in CN50

Due to the lack of any viable alternatives to ATF, these emissions are presently unavoidable and hereby, no interventions are proposed for abating aviation related emissions in the CN50 scenario. However, as technology develops and an alternative low-carbon aviation fuel (SAF) becomes economically viable, these emissions can be abated over and above abatement estimated in this analysis for the air transport sector.

1.3 Fisheries

Fuel consumption in fishing boats accounts for the third highest share of transport related emissions, at 3.31% (0.36 $MtCO_2e$). This analysis considers fisheries as a part of the transport sector, on account of emissions occurring due to fuel consumption during the operation of fishing vessels.

Kerala has a thriving fishing sector along its 590km coastline and a vast network of rivers and water streams. It also contributes 1.58% to the State's GDP. The State’s annual fish production is around 8,32,488 tonnes (5,81,422 marine and 2,51,066 inland), nearly 69.84% of which is from marine sources (Government of Kerala (A), 2024). This is enabled by its fleet of 43,298 boats, driven primarily by kerosene and diesel (Government of Kerala (B), 2022). Over the years, fuel consumption in fisheries is estimated to have declined, with a negative CAGR of 0.98%.

This is attributed to reduced kerosene usage, improved efficiency of new fishing boats, and rising fuel costs. *These trends are assumed to continue until 2050 in the BAU scenario.*

Methodology

Emission and energy projections in the fisheries sector of Kerala are based on fuel consumption and policy trends. For projecting the fuel consumption, individual fuel-wise (kerosene, petrol and diesel) growth rate in consumption is estimated. In the BAU scenario, historical fuel consumption for annual fish production (from 2005 onwards) has been analysed. The 2021 trends in fuel consumption are expected to continue throughout BAU. Fish production is also assumed to be constant until 2050.

Key Insights

This section provides projections for energy service demands and emissions in the fisheries sector.

Trends in Energy Demand and Emissions

In BAU, total energy demand is expected to increase from 4.81 PJ in 2021 to 6.26 PJ by 2050. Following the historical trend, kerosene in fishing boats is projected to decline, getting subsequently phased out by 2050. This gap would be met instead by diesel, with the consumption increasing from 3.78 PJ in 2021 to 6.03 PJ in BAU 2050. Petrol would be a supplementary fuel, demonstrating a marginal increase in consumption from 0.17 PJ in 2021 to 0.23 PJ in BAU 2050. Corresponding to energy demand, emissions in BAU would increase from 0.36 $MtCO_2e$ in 2021 to 0.47 $MtCO_2e$ in BAU 2050 *(Figure 12)*.

In the CN50 scenario, complete electrification of fishing boats, starting from solarisation of small size fleets by 2030 and gradually electrifying medium and large size fishing fleets by 2050, could avoid 60.01% of energy demand for fishing – reaching 2.51 PJ in 2050 while fully abating fishing related emissions.

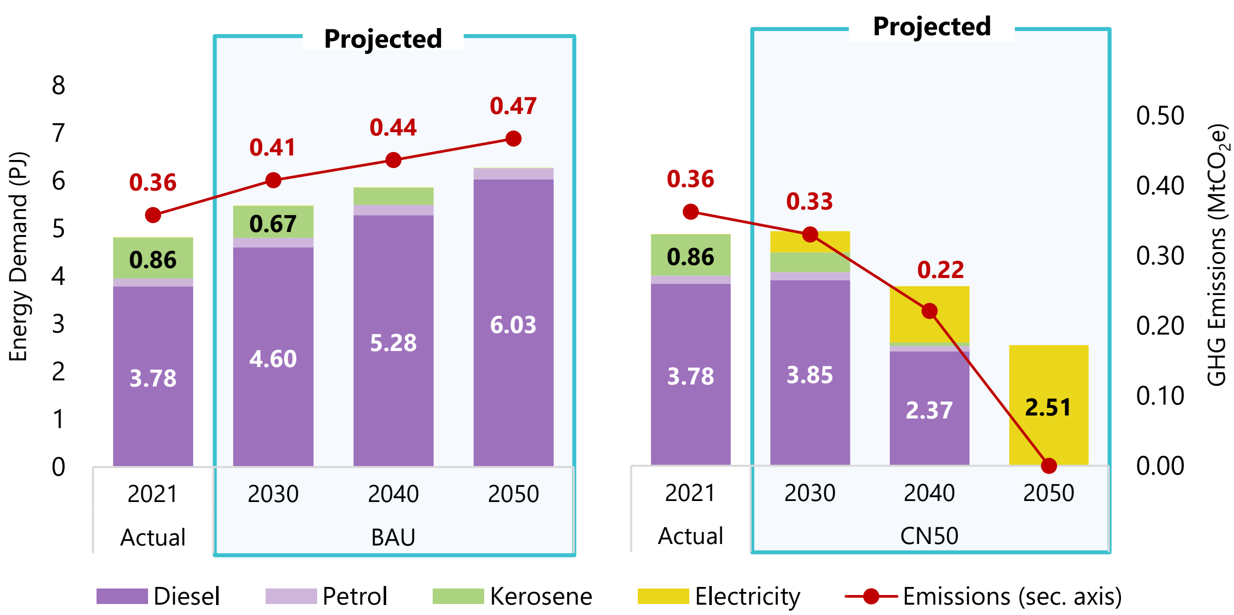


Figure 12: *Projected Energy Demand (PJ) and Emissions ($MtCO_2e$) of fisheries under BAU and CN50 scenarios.*

In BAU, following the historical trend, kerosene is expected to be phased out by 2050. The CN50 scenario assumes phasing out of diesel and petrol, and complete electrification of the fleet by 2050.

Box Item 3: Electrification of fishing boats is as economically viable in Kerala as it is essential for decarbonisation.

In Kerala, most fishers depend on motorised boats, where high fuel, maintenance, and repair costs significantly reduce their net incomes. Solar-assisted electric boats provide a cleaner and more economical alternative by using solar panels and electric motors instead of petrol or diesel. Studies suggest that adopting solar e-boats can increase fisherfolk incomes by up to 84%, primarily due to lower fuel and operating costs. Additionally, the total cost of ownership of a solar e-boat is estimated to be about 60% lower than that of a conventional petrol boat, owing to cheaper energy and reduced maintenance requirements (CEEW, 2023).

Key Interventions to Decarbonise Fisheries in CN50

Emissions from fisheries could be completely abated through,

- **Electrification of Fishing Boats:** Kerala has an existing fleet of 43,298 kerosene and diesel run boats. By electrifying even 20,000 mechanised fishing boats by 2050, 0.47 MtCO_2e of emissions from fisheries could be abated. This can be supported through technical and capacity support under government initiatives such as the Pradhan Mantri Matsya Sampada Yojana (PMMSY).

473.00 ktCO_2e of Decarbonisation Potential by 2050	**Stakeholders:** Fishing Community/Federations such as South Indian Federation of Fishermen Societies and Kerala Swatantra Matsya Thozhilali Federation, Ministry of Fisheries (Central) and State Fisheries Department & Other Agencies (policies, subsidies and capacity building), State Coastal Area Development Corporation (for community interventions)

1.4 Water Transport

Water transport in Kerala accounts for 0.36% (0.04 MtCO_2e) of transport related emissions. The State has a comprehensive inland water transport network encompassing 1683 water vessels, operating across its backwaters, rivers, and canals, primarily managed by the Kerala State Water Transport Department (SWTD) with modern services like the Kochi Water Metro enhancing connectivity for commuters and tourists alike[9]. Marine water transport in Kerala is relatively limited, focusing on regular passenger services from Kochi to the Lakshadweep Islands, as well as tourist sea cruises and cargo operations at key seaports such as Cochin Port and Vizhinjam Port.

Methodology

The demand for passenger transport in the water segment is projected by estimating the base year demand in BPKM and extrapolating it for the required future period. Passenger footfall growth is estimated using the Kerala Economic Review 2023 (Government of Kerala (B), 2024). For other water transport service categories, new stock additions and historical fuel demand are analysed and future projections are made based on past growth trends.

9 Data sourced from the State Water Department directly.

Tourism promotion is driving increased passenger footfall in the State (Government of Kerala (D), n.d.). The Working Group on Thirteenth Five Year Plan laid down a long-term perspective on purchase of new engines and reconstruction of old boats, acquisitions of fleet and augmentations of new ferry services, advanced tourist and cruise vessels, water taxi etc – indicating a policy push for revamping water transport in the State. The SWTD has further targeted replacing 50% of its conventional water transport fleet to solar boats, with the short-term plan including introduction of 15 new solar boats into the fleet (Government of Kerala (A), 2022) . These developments are also taken into consideration while projecting emissions, and developing decarbonisation strategy for the water transport segment.

Key Insights

Boats in Kerala carry nearly 20 million passengers per year (Government of India (D), 2022) (Table 10). During 2020-21, the average demand for water transport declined due to mobility restrictions during the COVID-19 pandemic – recovering partially to 0.21 BPKM in 2021 (Table 11). Considering segment growth and driven by robust policies that support a modal shift in passenger and freight segment, the average demand for water transport is projected to grow to 0.61 BPKM by 2050.

Table 10: Number of Inland Passengers Carried in Kerala

Year	No. of Passengers Carried (In 1000)	Total Length of the Rivers/ Canals/ Lakes in State (Km.)	Navigable Length (Km.)
2018-19	19739	2948.25	1926.87
2019-20	20535		
2020-21	8875*		
2021-22	19224.53		

Source: Statistics of Inland Water Transport 2021-22, Ministry of Ports, Shipping and Waterways. *COVID-19 impacted

Table 11: Water transport energy demand trends across scenarios

Parameter	Actual	BAU			CN50		
	2021	2030	2040	2050	2030	2040	2050
State Water Transport Demand - Passenger Segment (in BPKM)	0.21	0.33	0.45	0.61	0.33	0.45	0.61
Energy consumption in houseboats, speed boat and other services (PJ)	1.46	1.69	2.08	2.53	1.62	1.67	1.77

Trends in Energy Demand and Emissions in Water Transport

Congruent to increased demand for water transport (in BPKM), energy demand is expected to double from 1.46 PJ in 2021 to 2.53 PJ in 2050 under the BAU scenario. While emissions increase from 39.82 ktCO_2e in 2021 to 46.97 ktCO_2e in BAU 2050, the growth in emission is partially curtailed by adoption of electric and solar boats – driven by existing policy mandates and thrust on electrification.

In the CN50 scenario, the introduction of green hydrogen in the water transport fleet, combined with full electrification of vessels, is expected to completely abate water transport emissions by 2050 *(Figure 13)*.

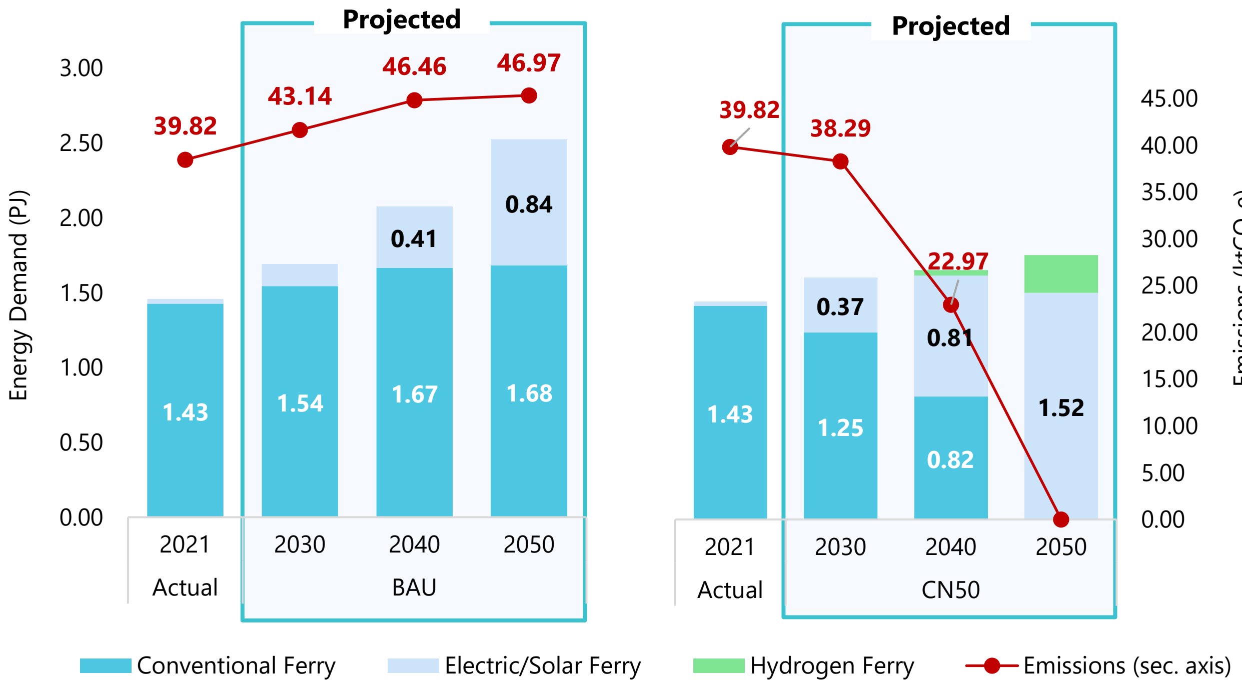


Figure 13: *Projected energy demand (PJ) and resultant emissions (ktCO2e) in water transport under BAU and CN50 scenario*

Emissions under BAU will continue to rise with the increase in ferried passengers. However, the rate of growth in GHG emissions slows due to the adoption of electric and solar boats supported by state policies in the BAU scenario.

Box Item 4: Policy mandate and mechanisms already exist to support electrification of water vessels in Kerala

Fuel-wise, the current fleet of passenger water vessels is heavily reliant on diesel, with electric boats making up a small but growing share of the total boat fleet in Kerala.[10] The State is mid-way through its fleet conversion program as announced in the State Budget 2022-23. In addition, Kochi's pioneering Water Metro project commenced operations in April 2023. The project envisions a fully integrated water transport system covering 78 km across 15 routes using electric hybrid boats, with construction advancing on multiple terminals.

Trends in Electricity Requirement in Water Transport

In BAU, partial adoption of electric/solar boats is expected to increase electricity demand in water transport from 9.00 GWh in 2021 to 234.00 GWh by 2050. In the CN50 scenario, full replacement of kerosene and diesel-based boats with electric/solar and hydrogen-powered boats, would increase electricity demand by 79.92% to 421.00 GWh in 2050 *(Figure 14)*.

10 As of 2025, the State Water Transport Department (SWTD) fleet comprised only 2-3 solar/electric ferries (models known as Aditya and Indra) out of the total stock of 71 boats.

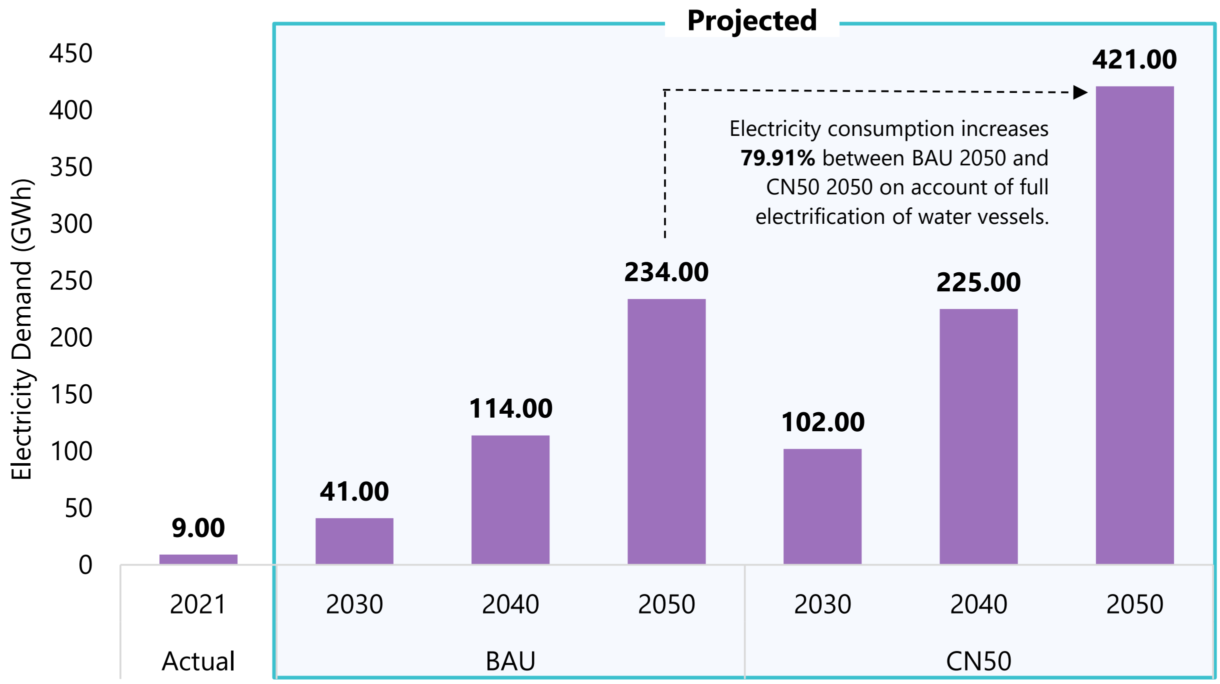


Figure 14: *Electricity demand (GWh) in water transport segment, in Kerala*

Box Item 5: Green hydrogen as an alternative fuel for shipping has already received strong impetus from Kerala Government.

In Kerala, the demand for green hydrogen and its derivatives is contextualised by the state's extensive inland water transport ecosystem, with a focus on vessel propulsion and bunkering infrastructure at major ports (Government of India (A), 2024). Driving factors in Kerala include daily ferry operations under the Kochi Water Metro (KMRL/KSWTD) and cargo movement via KSINC barges across 616 km of backwaters and canals – as well as growing coastal shipping potential through the ports of Kochi and Vizhinjam for passenger-cum-cargo and container traffic. The Kochi Green Hydrogen Valley Roadmap specifically advances this transition through planned hydrogen and green ammonia bunkering, storage facilities at Cochin Port, and pilot demonstrations for hydrogen-powered cargo barges and passenger ferries (MEC+ & GIZ, 2024). This is fully aligned with the Kerala Green Hydrogen Policy 2025 (Draft) that designates maritime applications as a priority sector and establishes a dedicated Hydrogen Hub at Kochi (Government of Kerala (C), 2025). Kerala has allocated ₹20 crore towards hydrogen valley development to enhance production, transport, and consumption of clean hydrogen in the state (Government of Kerala (B), 2023). This is in addition to ₹90 crores worth of central financial assistance, available per hydrogen valley project, under National Green Hydrogen Mission. As an early-stage intervention, this analysis estimates utilisation of 5-15 kt of pure green hydrogen in shipping by 2040.

Key Intervention to Decarbonise Water Transport

By replacing all existing ICE ferries with electric/solar and hydrogen-based counterparts by 2050, emissions from water transport can be fully abated.

46.97 ktCO_2e of Decarbonisation Potential by 2050	**Stakeholders:** State Transport Department (policies/subsidies), State Water Transport Department (SWTD), Industry (tech availability and infrastructure), Financiers (investment and capital)

1.5 Railways

Railways cover passenger and freight segments. The methodology for estimating current and future emissions from these segments, along with results are explained below.

1.5.1 Rail Passenger Segment

The State maintains a total railway route length of 1,047 km (Government of India (B), 2021). Railway operations in Kerala are jointly managed by three divisions of Southern Railway: Thiruvananthapuram, Palakkad, and Madurai. The Thiruvananthapuram division operates a total route length of 625 km, of which approximately 495 km lies within Kerala State and the remainder extends into Tamil Nadu.

All the railway lines passing through the State have been converted into broad gauge. Several expansion projects including line doubling, tripling, and new alignments are underway as part of the National Rail Plan. Kerala achieved 100% electrification of its 1,047 route kilometres by early 2025, well ahead of the national schedule (Government of India, 2026).

Methodology

Total energy requirement in the railway passenger segment is projected based on electricity and heat (diesel) consumption, using standard metrics (Zhou, et al., January 2007), which specify diesel consumption at 0.24 PJ/BPKM and electricity consumption at 0.12 PJ/BPKM. To estimate the energy supply, the traction and non-traction (administrative, buildings, and repair) segments of energy requirement were considered separately. Based on the route kilometres and passenger traffic, the passenger traffic is estimated in BPKM and compared against the benchmark energy requirement per BPKM to determine overall energy requirement (heat and electricity).

For future projections of passenger traffic, a univariate regression was used to correlate BPKM with population. This metric helps estimate the footfall of passenger movement both within and beyond the State boundary. A strong correlation was found, with an R^2 value of 0.94 between the two variables.

Key Insights

Passenger traffic is projected to increase from 35 BPKM in 2021 to 45 BPKM by 2050 based on historical growth. Total energy demand – which was 4.3 PJ in 2021 – is expected to increase to 4.5 PJ by 2050 corresponding to an increase in passenger traffic. While this would have otherwise led to a natural increase in diesel consumption in the railway passenger segment, Kerala’ achievement of full electrification of railways by March 2025 replaces the primary energy source from diesel to electricity, thereby, completely abating 0.04 $MtCO_2e$ of related emissions *(Figure 15)*. Further, the electricity requirement in the traction and non-traction segment is estimated to be 1190 GWh in 2050, with the traction segment accounting for ~81% (961 GWh) of total railway electricity consumption.

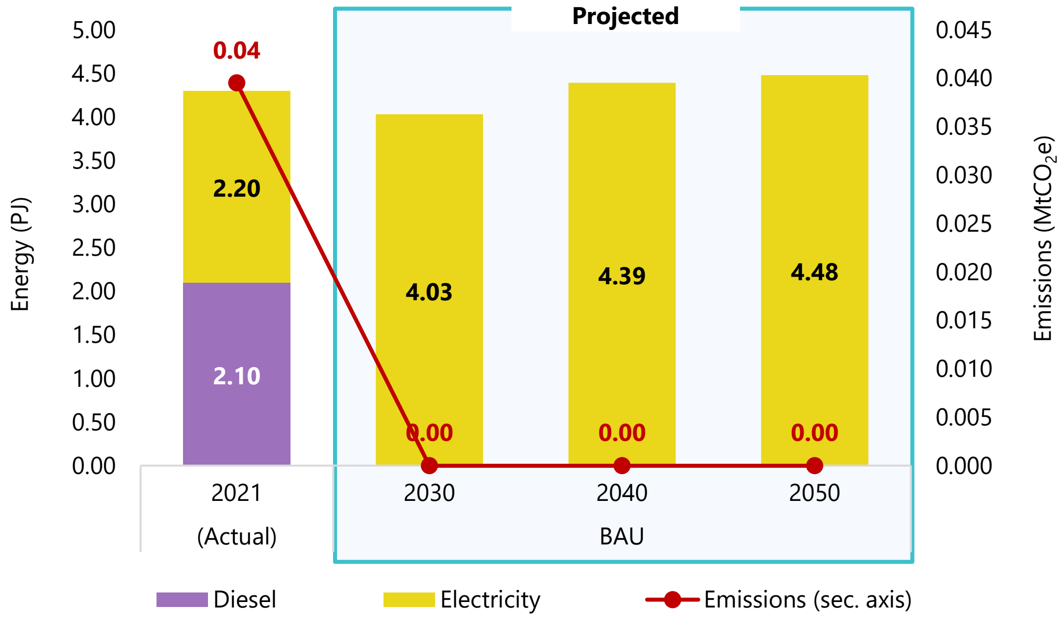


Figure 15: *Energy demand and resulting emissions in railway passenger segment under BAU scenario*

With electrification of railways by 2025, as per the State vision, emissions from the railway passenger segment are completely abated even in BAU scenario. An additional 639 GWh of electricity is, however, needed to meet the energy demand.

1.5.2 Rail Freight Segment

Railways' share across all modes of freight transportation in India has been declining since 1951, and a similar trend is observed in Kerala, where railway freight accounts for less than 50% of total freight transportation, with majority accounted for by road freight (Government of Kerala (B), 2021). This decline can be attributed to network congestion, high-density routes and last mile connectivity issues, leading to longer delivery lead times.

While the share of railway freight in total freight transportation continues to decline, a 6.43% year-on-year increase can be observed in freight traffic at the national level (Government of India (B), 2024). Regionally, Southern Railway caters to 33.9 million tonnes of freight traffic (Government of India (B), 2023).

At the State level, Kerala operates 72 freight train trips per day, with plans for doubling the traction lines and developing dedicated freight corridors (Government of Kerala, 2020). Furthermore, with the Indian government's focus on the 'Hungry for Cargo' mission, the modal share of railway freight is expected to increase to 45.00% by 2030, up from 27.00% in 2022. This is expected to improve ease of doing business and facilitate service delivery at competitive prices (Government of India (C), 2022).

Methodology

In the absence of any direct policy measure for freight in the State, the freight traffic growth rate for future projections in Kerala is estimated based on the 'Hungry for Cargo' mission. It is assumed that the total freight movement within the State will increase at the same rate witnessed in the country as well as that of the Southern Railways.

Total freight movement is measured in Net Tonne Kilometres (NTKM), which represents the weight of goods transported (excluding the weight of wagons) multiplied by the distance covered. Based on the assumption that the proportion of track length in Kerala corresponds to that of the Southern Railways, freight haulage in Kerala is estimated to have increased by 6.2% between

2012 and 2022 — matching the growth rate of the Southern Railways and to have reached 11.2 Million Net Tonne Kilometres (MNTKM).

Freight traffic in Kerala (MNTKM) is assumed to be primarily driven by the State's economy, particularly the industry and services sectors. Historically, freight demand has risen with increasing production and consumption, captured through the metric of sectoral Gross State Value Added (GSVA).

- **Industry GSVA** is a strong driver of freight demand due to the movement of raw materials and finished goods.
- **Services GSVA**, though less freight-intensive, also contributes through trade, logistics, warehousing, construction, and related activities.

A linear regression model is used where MNTKM is regressed against the combined GSVA of industry and services sectors. This relationship is established using historical data (e.g., 2012–2022), assuming that the elasticity (responsiveness) of freight demand with respect to economic growth remains stable throughout the projection period.

Key Insights

Freight movement is projected to increase almost 4-fold, leaping from 11.20 MNTKM in 2021 to 40.61 MNTKM in 2050. This will have a corresponding effect on energy and electricity demand – which is estimated to rise from 0.78 PJ in 2021 to 2.84 PJ in 2050, and 217.78 GWh in 2021 to 789.60 GWh in 2050 respectively *(Table 12)*. Similar to the passenger segment, electrification of railways in Kerala by 2025 has completely abated emissions from the railways freight segment. To move an extra 29.41 MNTKM by 2050, however, the system must add 571.82 GWh of clean electricity.

Table 12: Freight movement (MNTKM), energy demand (PJ) and electricity requirement (GWh) in railway freight segment by 2050 in Kerala

Parameter	2021	2030	2040	2050
Freight Movement (MNTKM)	11.20	16.56	26.24	40.61
Energy Requirement (PJ)	0.78	1.16	1.84	2.84
Electricity Requirement (in GWh)	217.78	321.96	510.11	789.60

Note: Both energy and electricity demand in the railway freight segment are projected to more than triple by 2050. As Indian Railways has already achieved full electrification of its broad-gauge network, railway operations in the State are effectively electrified. This positions railways as a low-emission freight mode, with future emissions dependent primarily on the carbon intensity of electricity. However, the projected growth in freight movement would require an additional 571.8 GWh of clean electricity by 2050.

Key Intervention to Decarbonise Railways

Railways are already projected to be fully electrified by 2025 – resulting in nil emissions even in BAU. The same trend is expected to follow in CN50, without any additional intervention.

Aggregate Results of Transport Sector

In the BAU scenario, air transport registers the highest increase in energy demand – from 10.54 PJ in 2021 to 57.90 PJ in 2050, while that in fisheries, railways and water transport increases but at a slower rate – from 4.81 PJ, 4.3 PJ and 1.46 PJ to 6.26 PJ, 4.48 PJ and 2.53 PJ respectively. Energy demand in road transport peaks in 2030 from 169.39 PJ in 2021 to 189.47 PJ in 2030, before declining to 145.50 on account of policy driven partial electrification of the road fleet.

The total energy demand in the transport sector follows the same trend – peaking in 2030 with 234.64 PJ from 192.50 PJ in 2021, before declining to 216.67 PJ in BAU 2050. *(Figure 16)* Congruently, emissions from transport sector are projected to increase from 10.97 $MtCO_2e$ in 2021 to 15.00 $MtCO_2e$ in 2030, and subsequently declining to 12.29 $MtCO_2e$ in BAU 2050 on account of partial electrification across transport in alignment with policy mandates. *(Figure 17)* The majority of residual emissions would remain in road transport (7.66 $MtCO_2e$) and air transport (4.11 $MtCO_2e$) *(Figure 18)*.

In the CN50 scenario, diesel and petrol demand is expected to be substituted by electricity due to the 100% adoption of EVs in road, and water transport (including houseboats). Since EVs have higher conversion efficiency compared to diesel- and petrol-fuelled vehicles, the overall energy demand is significantly lower in CN50 compared to the BAU scenario. Additionally, due to the limited options for fuel switching in aviation, ATF demand remains the same in both scenarios. As a result, 58.67% of projected transport related emissions could be abated in CN50 – reaching 5.09 $MtCO_2e$ in 2050. Energy demand would decline by 22.44% – to 168.05 PJ in 2050 due to electrification across transport sub-sectors.

Higher electrification rates in CN50 would also push electricity demand – from projected 9.25 TWh in BAU 2050 to 23.82 TWh in CN50 2050 *(Figure 19)*.

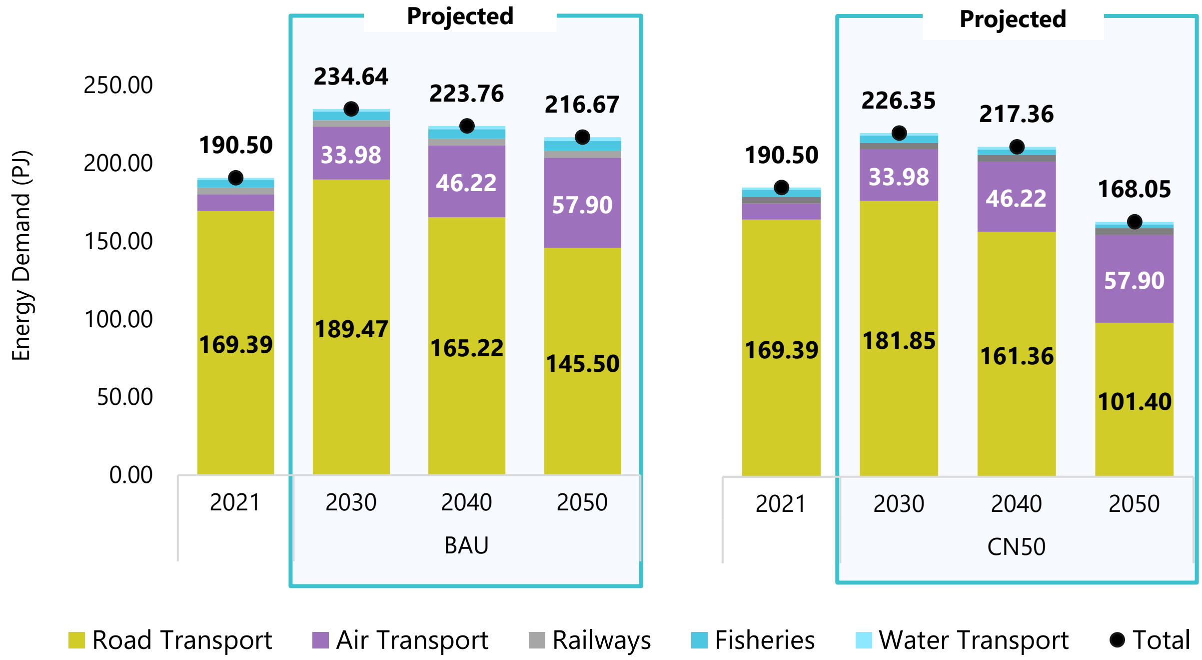


Figure 16: *Sub-sector wise energy demand (PJ) in transport sector*

Energy demand in road transport peaks in 2030, and declines thereafter due to partial electrification of road transport. The CN50 scenario proposes additional reduction in energy demand on account of near complete electrification in road transport, and complete electrification in fisheries and water transport.

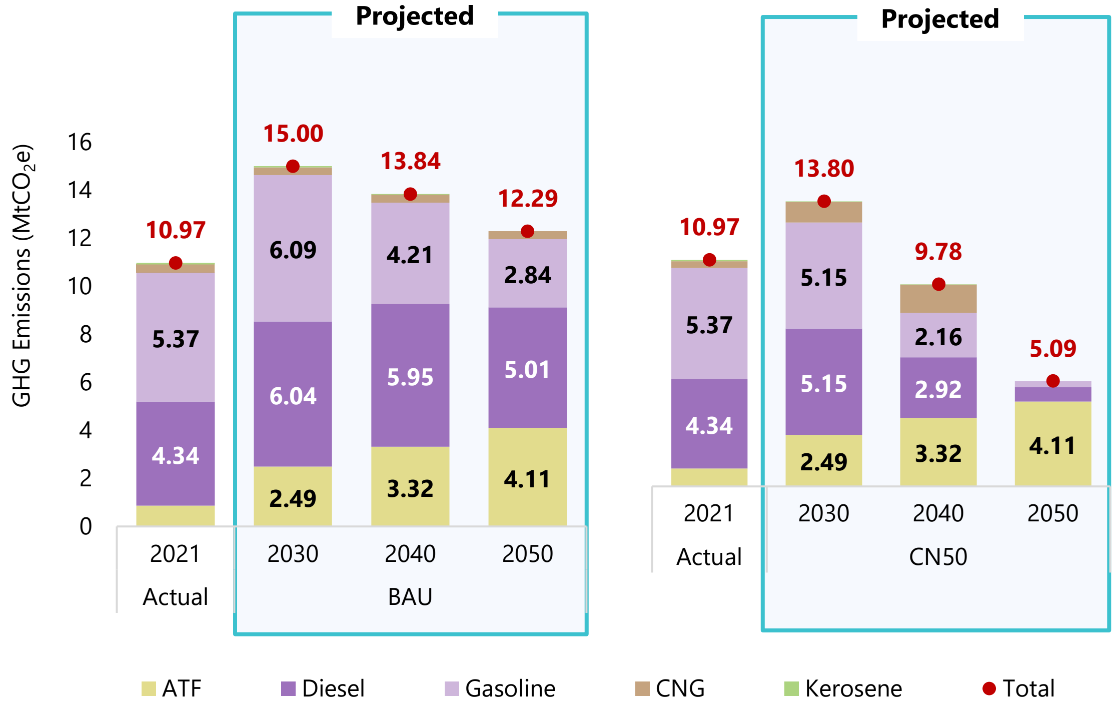


Figure 17: *Fuel wise transport emissions ($MtCO_2e$) in transport sector*

In BAU, emissions would remain in 2050 majorly on account of ATF, diesel and gasoline. In the CN50 scenario, diesel and gasoline are mostly replaced with electricity, leaving a slight residual on account of continued use in buses and HGVs. ATF emissions would remain as is, and could be subsequently captured as the technology for sustainable aviation fuel develops.

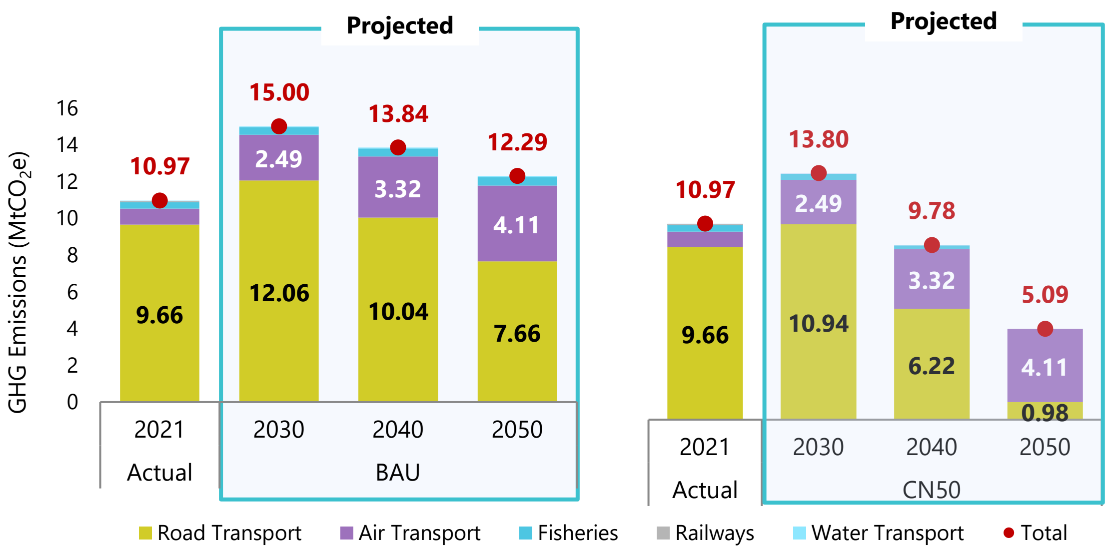


Figure 18: *Sub-sector wise transport emissions ($MtCO_2e$)*

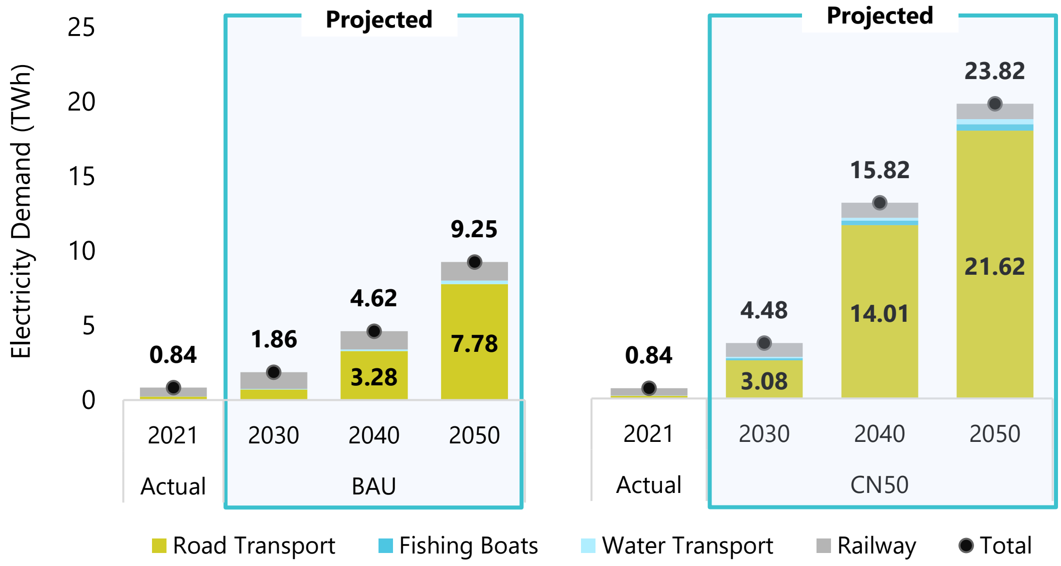


Figure 19: *Sub-sector wise electricity consumption in transport (TWh)*

Box Item 6: Bridging the ICE–EV Skills Gap: Challenges and Integrated Solutions for EV Ecosystem Development

Skill development is critical for India's EV ecosystem. Unlike ICE vehicles, EVs require specialised expertise in electronics, high-voltage systems, battery management, software diagnostics, and power electronics. The sector faces a **40–45% skills deficit** (Society of Indian Automobile Manufacturers (SIAM), 2025). SIAM estimates India will need **100,000–200,000** skilled EV professionals by 2030 to support 30% EV adoption. Yet **over 80%** of mechanics lack high-voltage training, **only 5–10%** of garages are equipped for EV service, and authorised centres remain concentrated in major cities. Bridging the gap requires large-scale reskilling of the ICE workforce, national certification frameworks, and strong government–industry–academia collaboration. Key priorities include expanding decentralised service networks, dedicated training centres, high-voltage safety standards, and advanced skills in BMS and power electronics — supported by targeted policies and financing — to build an inclusive, future-ready EV ecosystem across Tier 1–3 regions.

2. Buildings

Energy use in the buildings sector arises primarily from space cooling, heating, cooking and lighting in both residential and commercial buildings. Mitigation technology options for these sectors can be grouped into two broad categories: (1) efficiency improvements in existing and new building and equipment, and (2) switching to energy sources/appliances with lower GHG emissions. *The building sector analysis is presented below in three parts, namely residential buildings, commercial buildings and public services, and cooking.*

2.1 Residential Buildings

Residential energy use arises from cooling, cooking, heating, and appliances used at a household level. While cooking is predominantly fuelled by Liquefied Petroleum Gas (LPG) and Piped Natural Gas (PNG), the others are mostly powered by electricity. The analysis covers projected energy consumption across these except the cooking, which has been discussed separately.

Methodology

This analysis uses an appliance stock model to estimate residential electricity consumption across various appliance categories. Household appliance penetration data are sourced from the National Family Health Survey (NFHS) reports for Kerala pertaining to the years 2005-06, 2015-16, and 2019-21 (Government of India (F), n.d.). The annual growth rates of these appliances during these years are analysed to project household appliance penetration up to 2050.

For lighting devices, including incandescent bulbs, CFLs, and LEDs, household penetration data were obtained from the India Residential Energy Survey (IRES) (Agrawal et.al, 2024). Information on annual hours of usage and wattage for different appliances was retrieved from various secondary sources, enabling a detailed estimation of electricity consumption in the State.

The role of energy efficiency in evaluating residential electricity consumption was also assessed. In BAU, 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 the energy efficiency indicators (star labels) of these appliances. The CN50 scenario assumes higher efficiency levels, with applications rated above 3 stars.

Limitation

The Energy Performance Index (EPI) based approach was excluded from the residential sector analysis due to the lack of granular data on building typologies, floor space area, and the high variance in energy intensity across individual structures. Furthermore, the available BEE building EPI benchmarks (Bureau of Energy Efficiency (BEE), n.d.) alone are not sufficient to reflect modern efficiency standards or current HVAC penetration. Relying on these metrics and lack of data would introduce significant inaccuracies, making an EPI-led methodology unsuitable for the present analysis.

Key Insights

Kerala has achieved 100% electrification in the residential sector (Government of India (A), 2023). The sector has witnessed a significant surge in electricity consumption over the past decade, nearly doubling from 7.71 TWh in 2012 to 12.51 TWh in 2022 (Government of Kerala (A), n.d.). This increase can be attributed to a range of factors including improved energy access, rising per capita income, urbanisation, and shifting climatic conditions. Key insights emerging from the scenarios, particularly regarding trends in appliance penetration, emissions and electricity demand by 2050 are discussed below.

Trends in Appliance Penetration

In Kerala, the majority of households rely on ceiling fans for space cooling. However, as per capita income increases in the State and summers intensify, an increasing number of households are expected to adopt ACs in addition to, if not as a replacement of, ceiling fans. As a result, ACs are projected to experience faster growth than any other household appliance – increasing from 11 units per 100 households in 2021 to nearly 150 units per 100 households by 2050 (International Energy Agency, 2023). The historical increase in AC demand due to extreme heat in Kerala supports this model output.

Other appliances such as refrigerators, water heaters, washing machines, and other electronic devices (television, lights, mobile, laptop etc.)

are expected to register moderate growth. Thereby, contributing a smaller share of the residential electricity demand compared to ACs *(Figure 20)*.

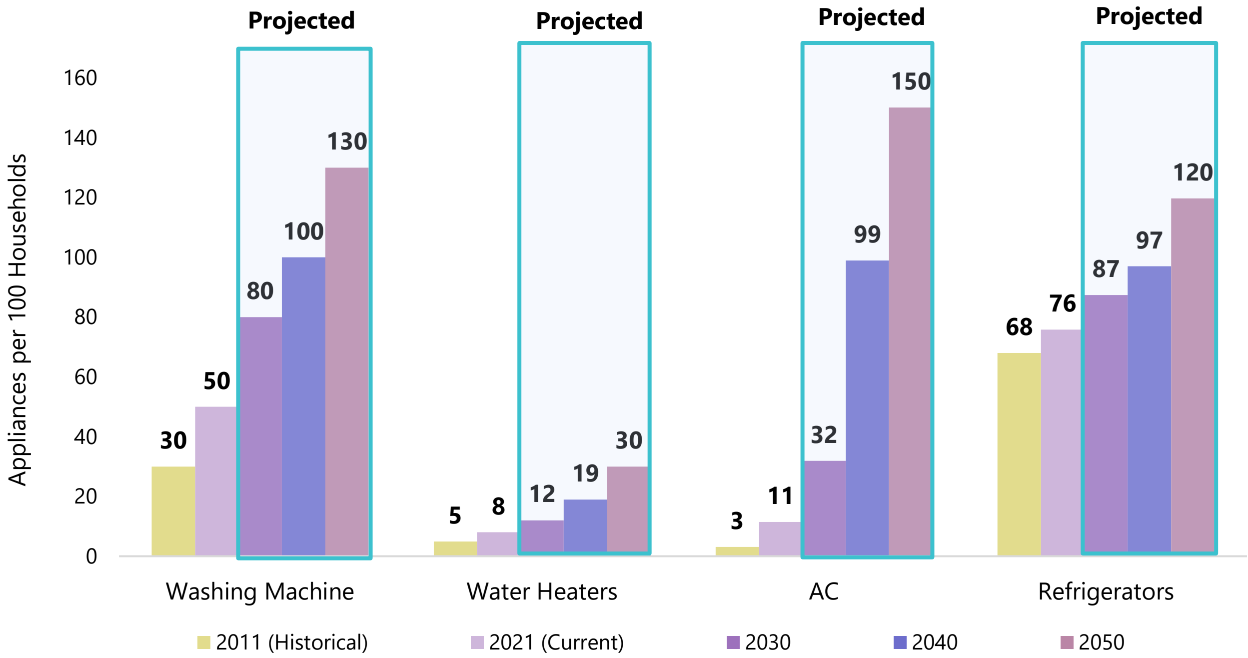


Figure 20: *Projected Appliance Penetration per 100 Households in Kerala*

AC demand – driven by increase in heat days and space cooling needs – is expected to register the most significant growth by 2050.

Notes:

a) 2011 data is based from Census 2011,

b) Appliance penetration in households would be the same in both BAU and CN50 scenarios. However, energy savings could be made on account of adoption of more energy efficient (3/5 star) appliances.

Trends in Electricity Demand

In BAU, with a higher penetration of appliances – particularly ACs, per household residential electricity consumption in Kerala would increase multifold – from 1289.02 kWh in 2021 to 3564.42 kWh in 2050. Per capita residential electricity consumption would also increase from 341.95 kWh in 2021 to 1082.68 kWh in 2050 *(Figure 21)*. Higher penetration of appliances and other necessities would translate to a three-fold increase in electricity consumption in residential buildings – from 12.51 TWh in 2021 to 39.33 TWh in 2050 *(Figure 22)*.

Space cooling – comprising 37.08% of electricity demand in 2021 – would continue to dominate electricity use in future years as well. In 2050, 61.45% of all projected electricity demand would be for space cooling. Furthermore, BAU scenario considers a complete transition from incandescent bulbs to LED lights by 2025, and from CFLs to LEDs by 2035, supported by the Filament Free Kerala initiative launched by the State Government to phase out filament bulbs (Government of Kerala (C), n.d.). This transition results in significant electricity savings in the lighting segment. These savings offset the increase in electricity demand arising from higher penetration of LEDs in the household – resulting in nearly similar lighting demand in 2050 (2.69 TWh) against 2021 baseline (2.76 TWh).

In the CN50 scenario, widespread adoption of energy-efficient (3/5 star-rated) air conditioners, refrigerators, and other appliances is projected to reduce electricity demand by 11.55% relative to BAU, bringing total consumption down to 34.79 TWh by 2050. Correspondingly, per household and per capita residential electricity consumption decline to 3,155.59 kWh and

958.50 kWh, respectively. Despite these efficiency gains, overall electricity demand remains significantly higher than 2021 levels, reflecting the strong influence of appliance ownership and cooling demand growth.

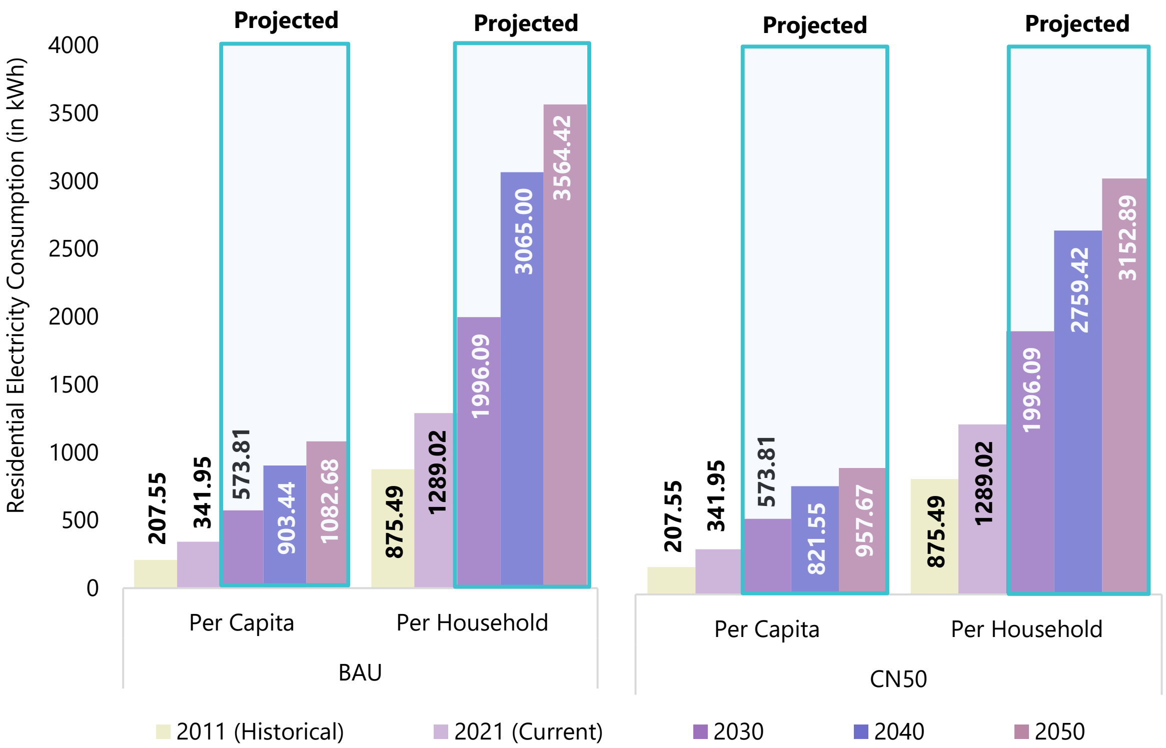


Figure 21: *Per Household and Per Capita Residential Electricity Consumption (kWh) in BAU and CN50 scenario*

Note: kWh is a better metric for representing electricity consumption at an individual or household level; while TWh is used commonly for wider scope (sectoral/district/state) | 1 TWh = 1000,000,000 kWh

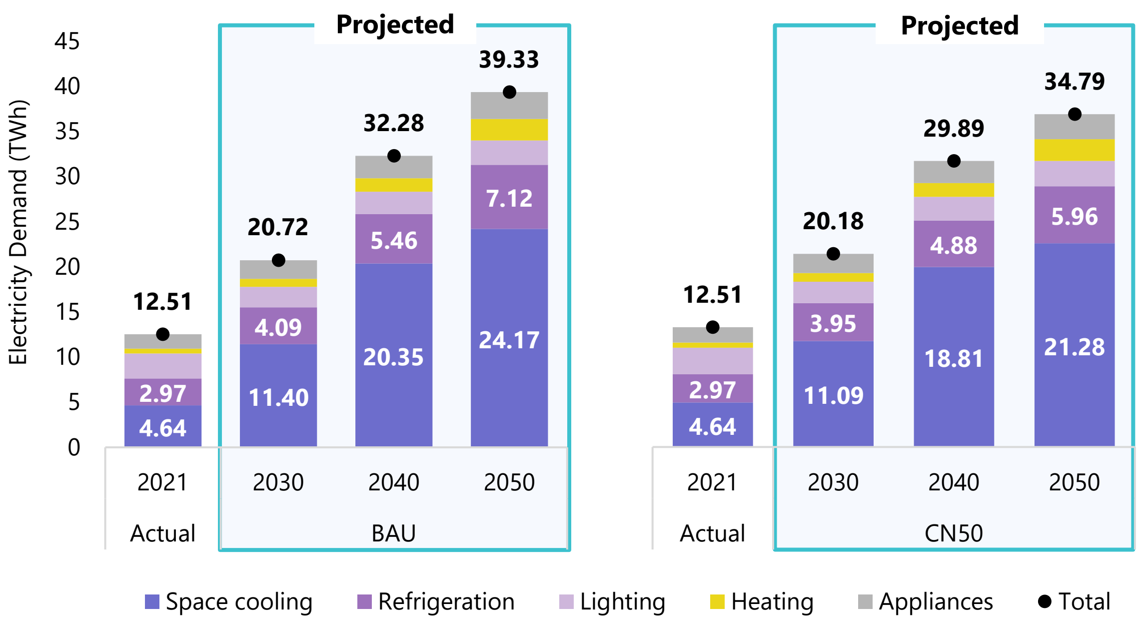


Figure 22: *Category wise electricity consumption (TWh) for residential buildings under BAU and CN50 scenario.*

Space cooling needs would increase eight-fold in the BAU scenario – from 4.64 TWh in 2021 to 24.17 TWh in 2050 – becoming the single largest driver of electricity demand growth in buildings.

Note: Appliances include TV, desktop, mobile, washing machine, fridge etc.

Key Interventions for Electricity Savings in Residential Buildings in CN50

As much as 11.55% of electricity can be saved through: -

- **Energy Efficient Cooling Solutions & Other Appliances:** Residences could be incentivised to adopt 3-5-star rated cooling appliances – approximately 3.13 crore BLDC fans, ~1.32 crore air conditioners, and 1.71 crore refrigerators by 2050. Similarly, energy efficient television, mobile and desktop could add to energy and emission avoidance in Kerala.

4.51 TWh (0.02 $MtCO_2e$)[11] of Electricity Savings Potential by 2050	**Stakeholders:** Individual users, Bureau of Energy Efficiency (Central - for enforcement), Kerala Energy Management Centre and Kerala State Electricity Board Limited (state policies and subsidies), Agency for New and Renewable Energy Research and Technology

- **Infrastructure Upgrades to Smart LED Lighting**: The IRES 2021 dataset suggests ~3.13 crore incandescent bulbs and CFL lights as operational in Kerala. In the CN50 scenario, these could be replaced with LED-based lights in residential buildings. Additionally, adaptive lighting solutions that adjust based on usage patterns and time of day can be explored to enhance energy savings.

0.03 TWh (0.02 $MtCO_2e$) of Electricity Savings Potential by 2050	**Stakeholders:** Individual users (for adoption) and Urban Local Bodies (implementation)

2.2 Commercial Buildings & Public Services

Commercial buildings and public services are a diverse category – comprising commercial establishments such as hotels, restaurants, hospitals, offices etc., public lighting, and other miscellaneous categories (licenses, railway traction, water works). Data centres are another emerging category – driven by the AI boom, and increasing adoption of AI driven solutions across sectors.

Electricity, natural gas, and diesel remain the primary energy sources in commercial buildings & public lighting, with consumption patterns varying based on building end-use.

Methodology

Past decade trends in electricity consumption serve as the basis for this analysis**.** Projections related to electricity demand are made by correlating historical electricity consumption with the economic value added by the service sector, using an econometric regression model.

Limitation: Due to lack of granular data on number of commercial buildings by type (hotels, hospitals, restaurants, offices etc.), and number of DG sets operational within these buildings in Kerala – this analysis is restricted to projecting electricity demand and does not account for fossil fuel use in the sector. The electricity projection for both BAU and CN50 are similar, since no additional intervention has been considered in the commercial sector.

11 This is Scope 2 emission. Similar pattern follows for the next intervention.

Furthermore, this analysis also does not account for the Energy Performance Index (EPI) based approach due to the lack of granular data on building typologies, building category wise floor space area, and a high variance in energy intensity across different commercial structures.

Key Insights

Between 2012 and 2021, electricity consumption increased by 6.61% in commercial buildings, 2.10% in public lighting and 12.11% in the miscellaneous category (licenses, railway traction, water works etc.).[12] In 2021, commercial buildings accounted for 82.47% (4.34 TWh) of total sectoral electricity demand of 5.27 TWh, followed by miscellaneous category at 10.37% (0.55 TWh), and public lighting at 7.16% (0.38 TWh). Data centre demand was negligible in 2021 due to its nascent stage of development.

By 2050, electricity demand in the sector is expected to grow five-fold to reach 26.03 TWh. Commercial buildings would continue to dominate – accounting for 78.69% (20.49 TWh) of this electricity demand. Data centres would be the second fastest growing segment, reaching 3.81 TWh in 2050 while supporting AI workloads between 2025 and 2050 *(Figure 23)*.

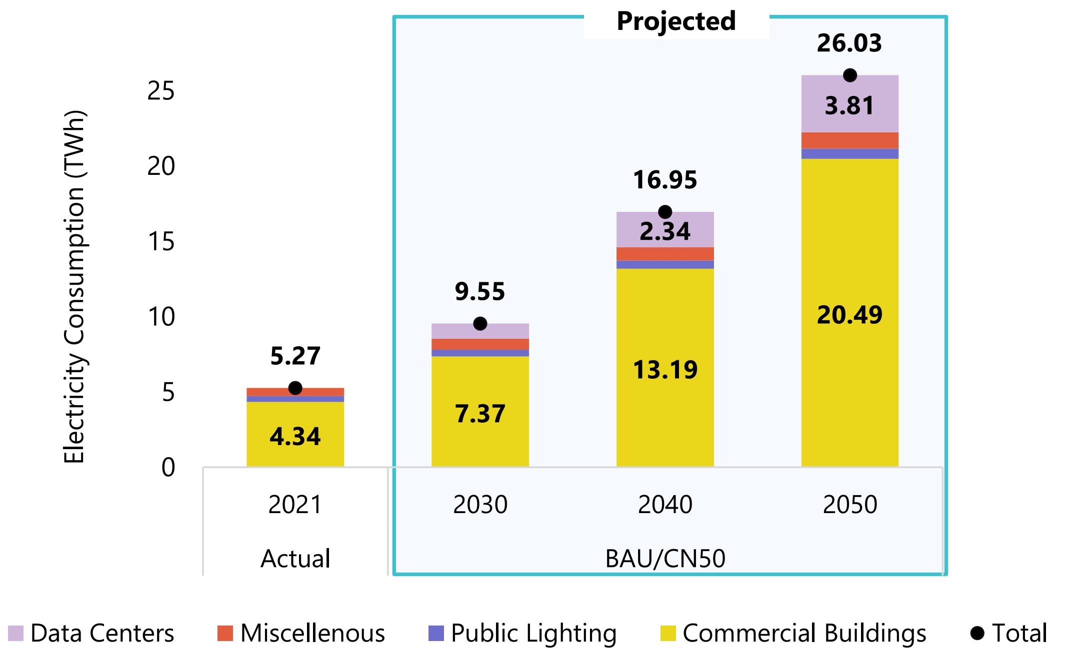


Figure 23: *Category-wise electricity consumption (TWh) in commercial buildings and public services*

Data centres will drive the majority of the electricity demand growth in the service sector, registering a 6-fold increase in electricity demand between 2024 and 2050.

Note: The BAU and CN50 scenario in case of commercial buildings and public services are the same.

12 The year 2012 is used as the base year due to the availability of consistent and comparable commercial sector electricity data; earlier datasets were excluded due to inconsistencies in data and classification.

Box Item 7: DG Sets Phase-Out and Replacement with BESS/Biodiesel in the Commercial Sector

In the commercial sector, diesel generator (DG) sets are widely used as a backup power source during grid outages. However, DG sets are highly polluting, emitting CO_2, N_2O, SO_2, and particulate matter, thereby contributing significantly to local air pollution. Estimating the mitigation from DG set phase out is constrained by the unavailability of DG set related data. This gap can be addressed through a dedicated assessment, with the target of phasing out all existing commercial DG sets, and replacing them with Battery Energy Storage Systems (BESS). When charged primarily from the grid and renewable sources such as rooftop solar PV, BESS provides a low-emission and efficient alternative for backup power.

In situations where BESS deployment is not technically feasible or economically viable – for instance, in commercial establishments with high backup power requirements, space limitations, or long-duration storage needs, DG sets are assumed to be retrofitted to run on biodiesel.

Box Item 8: Role of Data Centers in Kerala's Electricity Demand Growth

Data centres are highly electricity-intensive due to the combined needs of IT equipment and cooling infrastructure. While electricity demand in Kerala has been dominated by residential and commercial buildings, data centres are emerging as a fast-growing source of demand within the service sector. This growth is concentrated around major IT hubs such as Technopark (Thiruvananthapuram), Info Park (Kochi), and Cyberpark (Kozhikode), which are attracting investments in high-performance computing and data processing. In addition, a Memorandum of Understanding (MoU) for setting up of the World Trade Centre Thiruvananthapuram at Technopark was signed (Government of Kerala (E), n.d.). It is anticipated that the electricity consumption from these centres will contribute to a significant amount of electricity demand growth in the coming years.

The Information Technology sector in the State is expanding, supported by a robust network of Technoparks, Infopark, Cyber Park, and Technocity. With the commissioning of Phase III, Technopark has become one of the largest IT parks in India, encompassing 768.63 acres and 12.72 million square feet of built-up area (Government of Kerala (F), n.d.). Assuming that the effective area of data centres accounts for ~10-12% of total floor area, it is estimated that the electricity demand from data centres would grow from 0.63 TWh to 3.81 TWh, registering a multifold increase between 2024 and 2050.

2.3 Cooking

Kerala households rely on multiple fuel sources for cooking. Fuel preferences vary across households, leading to diverse cooking energy needs. This type of fuel stacking is outside the scope of this analysis due to the complexity of modelling fuel substitution in such scenarios. Like most decarbonisation analyses, this study instead focuses on primary fuel consumption.

Methodology

To estimate cooking energy requirements up to 2050, the final cooking energy consumption (i.e., actual energy used for cooking, after accounting for losses), is estimated. Useful Energy (UE) is used as the key metric to calculate per capita cooking energy requirement. After accounting for LPG and electricity penetration in cooking energy demand, the remaining share is attributed to biomass. Based on the LPG and firewood consumed in the baseline year, the UE value is calibrated for the State, and projected to 2050. The cook stove thermal efficiency is used to estimate the primary energy requirement and project it under both the BAU and CN50 scenarios up to 2050.

Key Insights

Trends in Energy Demand

In 2021, total energy demand for cooking in Kerala stood at 46.55 PJ. Fuel-wise, LPG dominated the cooking energy mix in urban households, accounting for 88.04% of total cooking fuel consumption in the State. Alongside LPG, biomass – the second most dominant cooking fuel with 10.05% of total cooking fuel consumption – played an important role in meeting cooking energy demand, particularly in rural households and in commercial establishments such as hotels and restaurants, where it remains a cheap and readily available fuel. PNG emerged as a new option, albeit with limited penetration, while electricity's share in cooking was negligible.

In BAU, energy demand for cooking is expected to mimic the growth in population and commercial activities – increasing from 46.55 PJ in 2021 to 48.17 PJ in BAU 2050. In terms of fuel mix, the shares of biomass and electric cooking are assumed to remain constant, whereas approximately 15.00% of the LPG mix is substituted by PNG, driven by expanding CGD network access in urban areas.

Contrary to BAU, in CN50, reliance on biomass is projected to be completely eliminated by 2030, and the share of LPG in the cooking fuel mix is expected to decline from 73.93% in BAU 2050 to a near-marginal (5.88%) level by 2050. This transition is driven by two key factors. First, electricity becomes increasingly cost-competitive with liquid fuels, leading to a greater uptake of electric cooking. Second, the expansion of the city gas distribution (CGD) network provides urban households with greater access to natural gas, further boosting its adoption across the state. This would result in a much higher reliance on both PNG and electricity as cooking fuels – increasing their share to 59.09% (22.86 PJ) and 35.04% (13.55 PJ) respectively in 2050. This replacement of highly intensive LPG with much more energy efficient fuels would reduce the energy demand by 19.70% – to 38.68 PJ in 2050 *(Figure 24)*. Further, under the CN50 scenario, electricity demand for cooking is projected to rise from a negligible level at present to approximately 3.76 TWh by 2050.

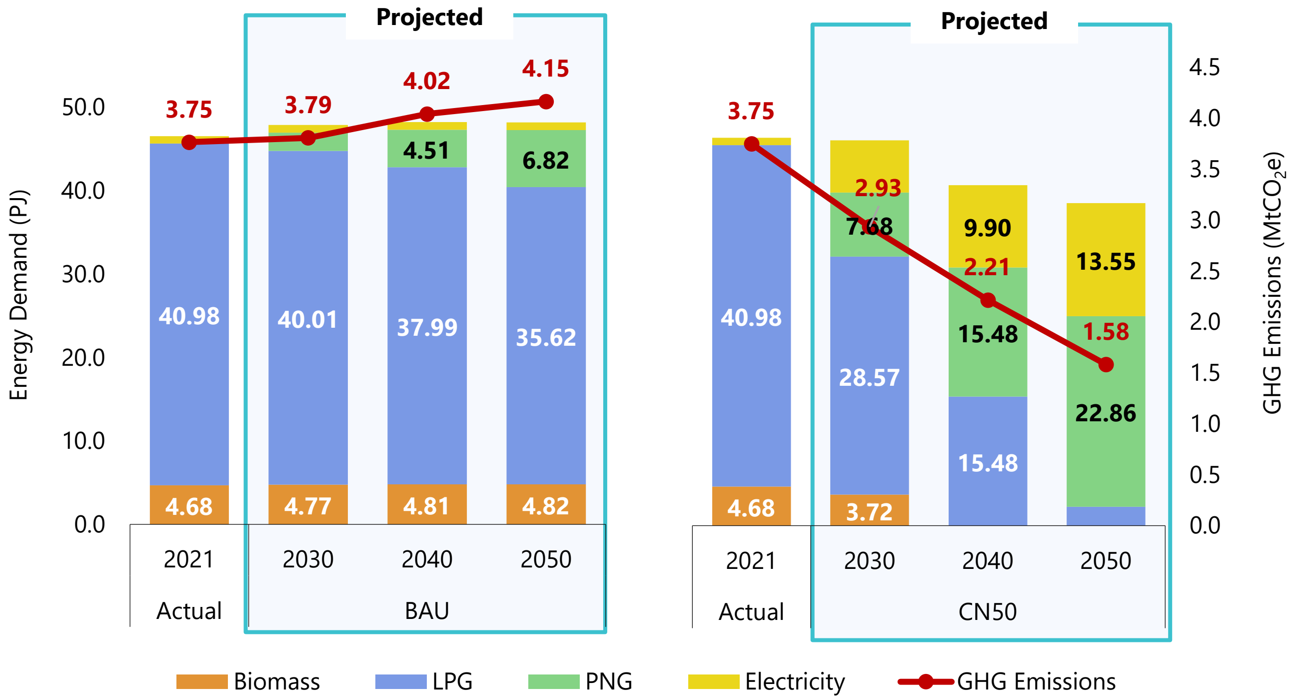


Figure 24: *Fuel wise energy demand (PJ) and emissions ($MtCO_2e$) in cooking sector*

In CN50, PNG and electricity would be two prominent cooking fuels. With higher efficiency than LPG, this fuel switching could save energy demand while also mitigating potential cooking related emissions.

Trends in Emissions

Kerala recorded a baseline emission of 3.75 $MtCO_2e$ from cooking in 2021 – attributed to its LPG and biomass reliant cooking mix. In BAU, while PNG substitutes a portion of LPG, the substitution is marginal with cooking related emissions increasing to 4.15 $MtCO_2e$.[13] In CN50, with the phase out of biomass as a cooking fuel by 2035, higher substitution of LPG with PNG, and higher adoption of electricity as a cooking fuel – about 61.93% of projected emissions could be abated by 2050. A residual of 1.58 $MtCO_2e$ would remain on account of continued LPG and PNG usage.

Key Interventions to Decarbonise Cooking in CN50

About 61.93% or 2.57 $MtCO_2e$ of cooking related emissions can be saved by adopting clean cooking solutions by 2050. This includes,

- **Adoption of High-Efficiency Electric Cooking Appliances**: This could be achieved by subsidising induction and electric cookstoves for approximately 10.50 lakh (10.00%) households by 2030 and around 55.17 (50.00%) lakhs households by 2050, with support from the National Energy Cooking Program (NECP) and other government schemes/policies.

13 As per guidelines of the Intergovernmental Panel on Climate Change, emissions from biomass combustion are classified as **biogenic**, meaning the CO_2 released during burning is part of the natural carbon cycle and was previously absorbed during plant growth. Due to this, biomass is not captured in cooking emissions (which includes emissions due to LPG and PNG use only) while it continues to be represented in cooking related energy demand.

1.64 $MtCO_2e$ of Decarbonisation Potential by 2050	**Stakeholders:** Individual Users (for adoption) and Urban Local Bodies (implementation), Kerala Energy Management Centre and Kerala State Electricity Board Limited (policies and incentives)

- **Accelerating PNG Infrastructure Development and Subsidising Initial Connections:** By introducing credit-linked instalment mechanisms to boost new initial connection charges, the State can increase the share of PNG in cooking to 50% by 2050.

Furthermore, City Gas Distribution (CGD) networks can be expanded to reduce reliance on bottled LPG for cooking by leveraging imported LNG based supply networks where feasible, particularly in urban settings.

0.93 $MtCO_2e$ of Decarbonisation Potential by 2050	**Stakeholders:** Individual Users (for adoption) and Urban Local Bodies (implementation), industry partners for infrastructure developments

Aggregate Result of Building Sector

Total Primary Energy Supply (TPES)[14] of the building sector accounts for 29.61% the total energy supplied in the State.

In BAU, it more than doubles – from 110.64 PJ in 2021 to 283.48 PJ in 2050 on account of higher electricity demand, driven majorly by increased number of heat days and need for cooling. BAU also witnesses a 15% shift from LPG to PNG, while biomass-based energy demand remains constant.

In CN50, efficiency measures in residential buildings and commercial services reduce the aggregate energy demand marginally – reaching 257.65 PJ in 2050. Further, LPG would be mostly phased out – with a residual share of 0.88% on account of continued LPG use in some households. Correspondingly, buildings' related emissions – which increased from 3.75 $MtCO_2e$ in 2021 to 4.15 $MtCO_2e$ in BAU 2050 – could be reduced to 1.58 $MtCO_2e$ in 2050 under the CN50 scenario.

14 Total Energy supply (TES) or Total Primary Energy supply (TPES) refers to the total energy consumption by end uses, such as the residential, commercial, transport, and industrial sectors, along with losses due to system inefficiencies during energy conversion.

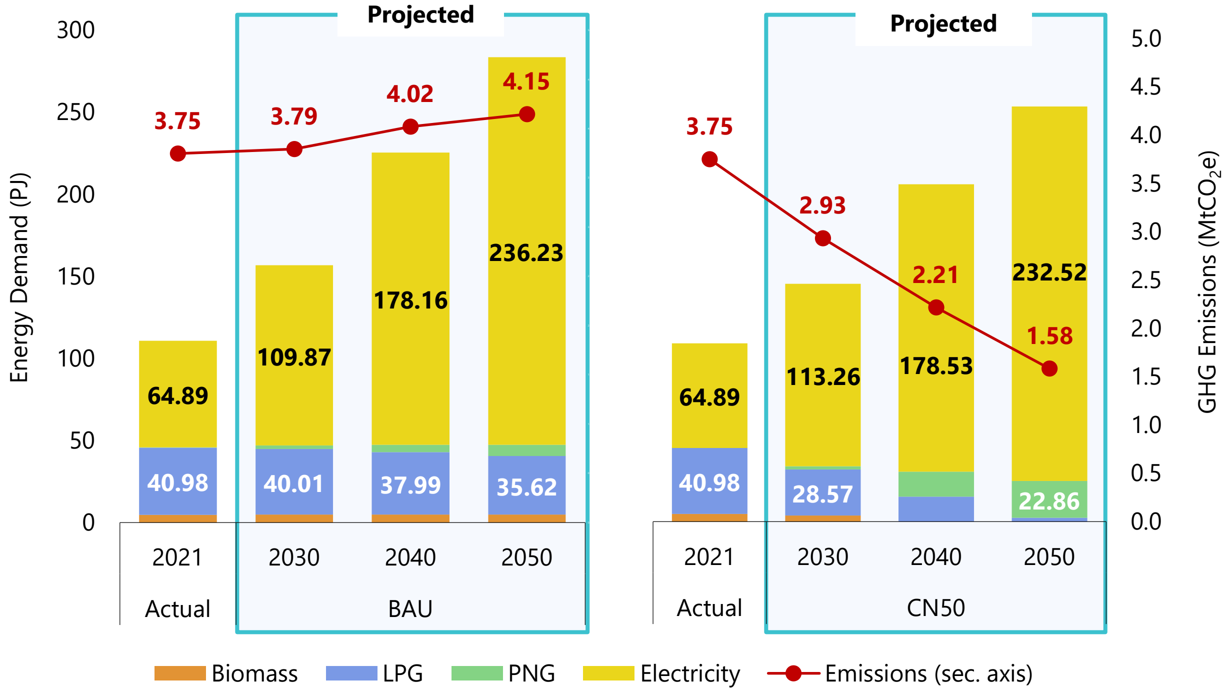


Figure 25: *Fuel wise energy demand and emissions in the building sector of Kerala, in PJ and $MtCO_2e$*

Note: Electricity in Energy demand (PJ) includes residential buildings, commercial buildings and cooking. Other fuels (biomass, LPG and PNG) are cooking specific only. Emissions represented in the graph depict Scope 1 only.

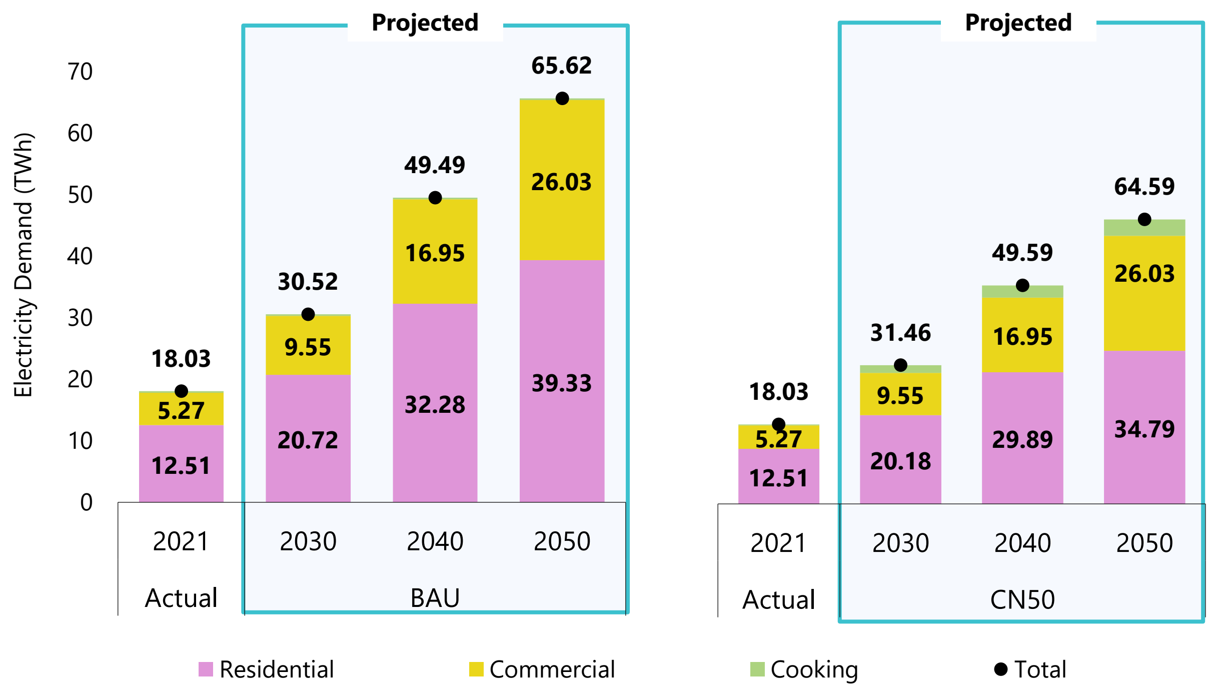


Figure 26: *Aggregate electricity demand (TWh) in building sector, including cooking*

Notes:

- Increase in electricity demand due to higher penetration of appliances and space cooling needs is counterbalanced by energy savings due to adoption of energy efficient fans, bulbs, ACs etc.
- While direct emissions from cooking fuels decline under the CN50 scenario, increased electrification may lead to higher indirect (Scope 2) emissions unless accompanied by progressive decarbonisation of the electricity grid.

Box Item 9: Renewable energy integration for decarbonising the electricity use in buildings

Higher adoption of electric cookstoves and increased appliance use is projected to result in a multifold increase in electricity demand in Kerala, which would result in a much higher Scope 2 emissions. This is considering that the State imports coal-based electricity to meet its demand. By encouraging renewable energy integration, the State can not only substantially avoid Scope 2 emissions, but also become self-reliant in meeting its energy requirements.

This could be done through,

- Conducting an in-depth assessment of rooftop potential in Kerala. In addition to reducing grid dependence, rooftop solar panels offer the co-benefit of lowering indoor temperatures by providing shade, thereby enhancing thermal comfort and resilience during heat waves.
- Mandating or incentivising solar PV installations in residential and commercial buildings, aiming to cover at least 30.00% electricity demand from on-site renewables by 2030. In existing and new commercial buildings, this could be aligned with ECBC/GRIHA standards compliance.

A detailed analysis of the potential of achieving 100% RE by 2040 is provided in Part III of this report.

3. Agriculture Energy (Irrigation and Land Preparation)[15]

Kerala's primary sector contributes around 8.06% to Kerala's Gross State Value Added (GSVA), with agriculture and allied activities alone accounting for 7.64% (Government of Kerala (A), 2026). The State's agricultural structure differs from many other Indian states, with a strong emphasis on plantation and cash crops rather than food grains. Of the State's total geographical area of 38.86 lakh hectares, about 25.15 lakh hectares are under cultivation. Within this cropped area, coconut leads with a 30.44% share, followed by rubber at 21.78%, while plantation crops collectively account for 28.22%, reflecting the deeply commercial character of Kerala's farming landscape. Despite this structural distinction, the sector has shown encouraging signs of resilience — agriculture and allied activities recorded a growth of approximately 2.14% in 2024–25 w.r.t. previous year (2023-24), signalling a meaningful recovery in the primary sector (Government of Kerala (A), 2026).

Methodology

The agricultural energy use analysis accounts for change in energy demand and emissions, on account of irrigation and land preparation. By analysing historical changes in crop yields and gross irrigated area, the irrigation water requirements and consequently, the electricity needed for pumping water to the fields have been estimated (Reserve Bank of India (RBI), 2025) *(Figure 27)*. Apart from irrigation pumpsets, fuel consumption in agricultural machinery was estimated based on the existing and projected future number of tractors and tillers in the State.

15 Please see Chapter 4 for specific assessments for agricultural practices and livestock. To keep the reporting consistency emission pathways related to energy use in agriculture are considered separately and given under the energy sector

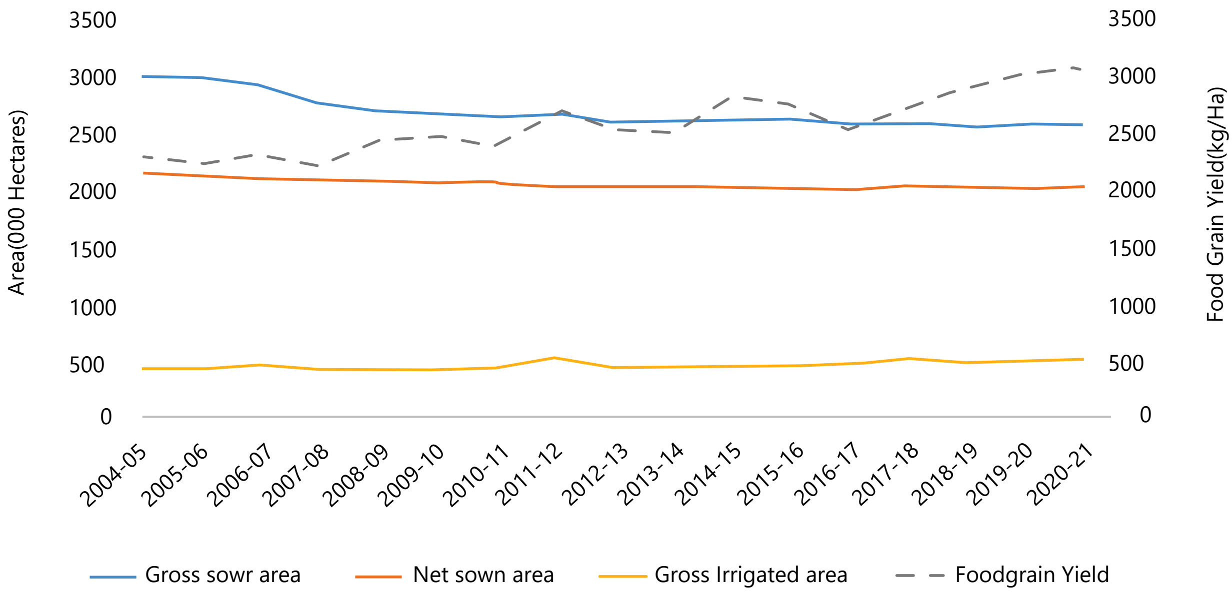


Figure 27: *Change in agricultural land use and food grain yield in Kerala*

Source: Handbook of Statistics on Indian States, Reserve Bank of India

Kerala's gross sown area, net sown area, and gross irrigated area have remained nearly constant historically, while food grain yield has risen steadily from ~2,300 to over 3,000 Kg/Ha, driven by adoption of HYV seeds, improved fertilizers, and better irrigation techniques.

Key Insights

This section covers key insights from the projection of agricultural energy related emissions and electricity demand under the BAU and CN50 scenarios.

Trends in Electricity Demand

In 2021, electricity demand from irrigation activities amounted to 379.36 GWh (0.37 billion units), driven by approximately 5.50 lakh irrigation pump sets and representing only 1.48% of the total electricity requirement in the State. In BAU, the total number of electric irrigation pumps is projected to increase to about 6.65 lakh by 2050, with only around 5.00% (~35,000) being decentralised solar-powered pumps. This increase in pump numbers correlates with the growing demands for water supply in year-round agriculture activities. Subsequently, electricity consumption for irrigation activities is anticipated to increase steadily, reaching 409.98 GWh by 2030 and 480.80 GWh by 2050. This could be further accelerated under the CN50 scenario through the complete transition of 16,041[16] diesel run irrigation pumps to solar-powered/electric pumps by 2030, in convergence with schemes at center and state level.[17]

Similar electrification efforts could be undertaken to reduce emissions from agricultural machinery led operations. The State's current stock of ~14,000 tractors and tillers are projected to increase to ~22,000 in 2050 – all of which are diesel-run (Government of India, 2016). In CN50, a complete electrification of agricultural machinery is expected to increase overall electricity demand while simultaneously reducing the total energy

16 The latest dataset available for fuel wise irrigation pumpset is Agriculture Input Survey 2016-17. Same numbers are assumed for 2021 due to lack of revised survey data. (Government of India, 2016)

17 PM KUSUM, which was aimed at promoting adoption of solar/electric pumpsets, expired in March 2026. A subsequent version, PM KUSUM 2.0 is under work, with an additional component of battery storage for agricultural energy.

requirement due to enhanced efficiency of electric equipment. Higher electrification to meet irrigation and land preparation needs is projected to increase electricity demand to 795.63 GWh by 2050 *(Figure 28)*.

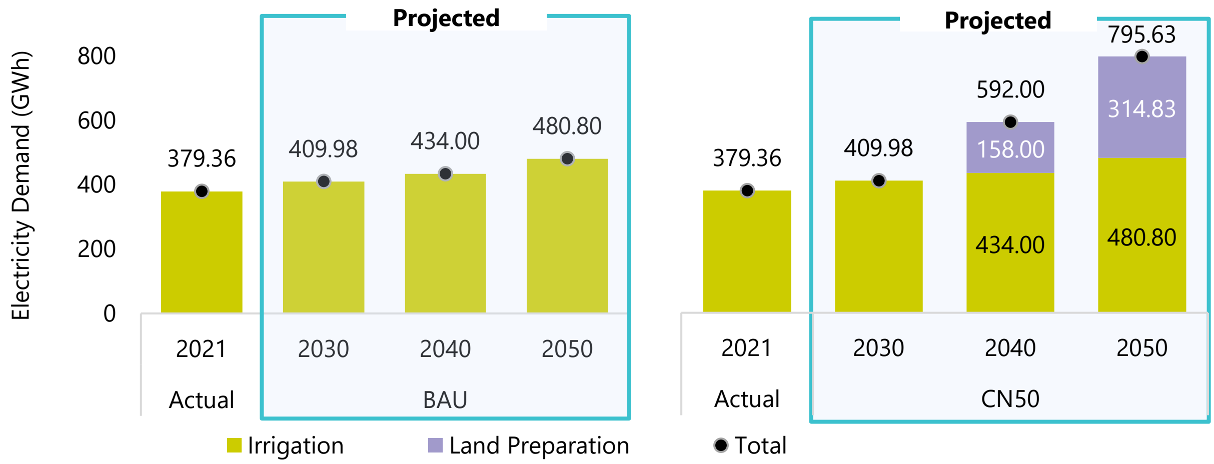


Figure 28: *Current and projected electricity demand (in GWh) in agriculture sector*

Electrification of irrigational pump sets and agricultural machinery is expected to double electricity demand by 2050 under the CN50 scenario

Trends in Energy Demand and Emissions

Energy demand in the agriculture sector is still heavily reliant on diesel as a fuel. In 2021, energy demand via pump sets, tractors and tillers were 6.00 PJ. While agriculture represents a miniscule portion of total emissions, emissions from the sector are expected to rise by 17.54% than 2021 level – from 115.75 $ktCO_2e$ to 135.88 $ktCO_2e$ by 2050 in the BAU scenario *(Figure 29)*. With the complete electrification of irrigation pumping, land preparation and harvesting, emissions reach zero in the CN50 by 2050.

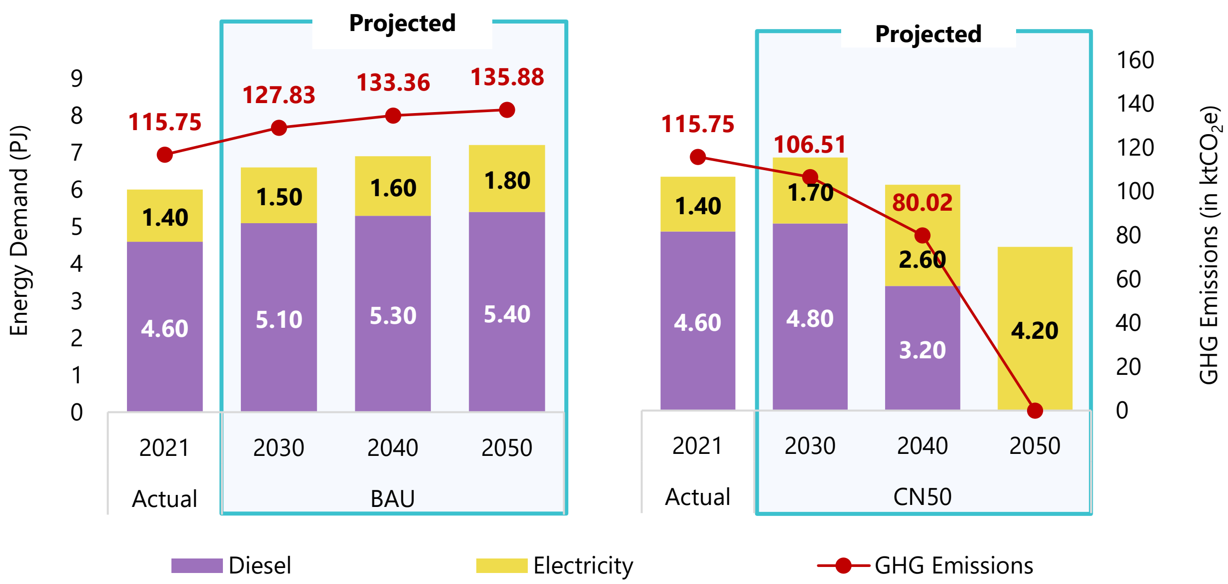


Figure 29: *Aggregate energy requirement (PJ) and GHG Emissions ($ktCO_2e$) in agriculture sector*

Energy-efficient electric pump sets, solar pumps and electric agro-machinery in CN50 will reduce energy demand (PJ) and GHG emissions to zero by 2050.

Note: Emissions in agriculture energy are provided in $ktCO_2e$, for readability purposes. These are aggregated to $MtCO_2e$

Box Item 10: Bioenergy Pathways in Kerala: Resource Utilisation, Power Generation, and GHG Abatement Potential

Bioenergy pathways, while affected by economic and supply sided barriers, could eventually play a supporting role in Kerala's carbon neutrality goal. As biomass aggregation is made efficient, supply-demand mismatches are resolved, technology becomes cost competitive, and commercialisation hurdles are addressed, bioenergy pathways could result in additional abatements, over and above the ones mentioned in Carbon Neutral Kerala by 2050 plan.

Two interventions that deserve special attention are: -

- **Biogas Generation from Livestock Waste for Power and Cooking Energy Substitution:** Kerala generates nearly 4.00–6.00 MMT of livestock waste annually (Government of Kerala (E), 2022). This can be converted into biogas through anaerobic digestion, corresponding to a potential of about 0.30–0.40 million cubic metres per day (MCM/day). If channelled into power generation, this could produce an average of 35.00–50.00 MW of electricity (assuming 60.00% utilisation). Alternatively, if the biogas is utilised for cooking, it is projected to meet the energy needs of about 5–8 lakh households (nearly 5.00% of Kerala's households), replacing 3–5 million domestic LPG cylinders annually. Harnessing this potential could result in an abatement of lead to 0.20–0.30 $MtCO_2e$ abatement per year under CN50.
- **Electricity Generation and Emission Mitigation through Municipal Solid Waste (MSW)-to-Energy:** Kerala generates 3.70 million tonnes of municipal solid waste annually (Kerala Solid Waste Management Project (KSWMP), n.d.), of which about 69.00% is biodegradable and suitable for waste-to-energy conversion. Assuming 60.00% utilisation, the State could generate ~472.00 GWh of electricity annually, equivalent to an installed capacity of 90.00–100.00 MW.

The associated GHG abatement potential from MSW-to-energy is estimated at 0.30-0.40 $MtCO_2e$ per year, excluding additional benefits from avoided landfill methane emissions.

Key Interventions to Decarbonise Agricultural Energy Use in CN50

Emissions from the agricultural energy sector can be completely abated through the following interventions: -

- **Promotion of Renewable Energy Solutions for Irrigation:**
  - *Solar-Powered Irrigation Systems:* Replacing 16,041 existing diesel pump sets with solar pumps by 2030.
  - *Agrivoltaics:* Exploring potentials for implementing agrivoltaic 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.

21.49 $ktCO_2e$
of Decarbonisation Potential by 2050

Stakeholders: Individual Farmers / Farmer Producer Organisation (FPO) / Water User Associations, State Agriculture Development and Farmer's Welfare Department, Kerala State Electricity Board Limited (KSEBL), ANERT, EMC

- **Transitioning from diesel machineries to electric machineries in agriculture:** Promoting electric tractors by targeting at least 30.00% of new tractor sales to be electric by 2035, supported by tailored financing solutions from agricultural banks and financial institutions. Additionally, transition all ~22000 projected diesel-based tractors and tillers to electric by 2050.

114.56 ktCO_2e of Decarbonisation Potential by 2050	**Stakeholders:** Individual Farmers / Farmer Producer Organisation (FPO) / Water User Associations, State Agriculture Development and Farmer's Welfare Department, Kerala State Electricity Board Limited (KSEBL), ANERT, EMC

4. Industrial Energy Use

Kerala's industrial sector constitutes the secondary segment of the economy, encompassing manufacturing, construction, mining and quarrying. As per the Kerala Economic Review 2025, the secondary sector accounted for 28.49% of Gross State Value Added (GSVA) at constant prices in 2024-25 (Quick Estimate). Within this, manufacturing accounted for 13.08% and construction for 14.05% of real GSVA in 2024-25. However, the services sector dominates the State's economy, with a share of 63.45% of GSVA in 2022-23 (Government of India (D), 2025).

Major traditional industries include coir, cashew processing, handloom, khadi, and rubber-based products, while emerging priority sectors under the Kerala Industrial Policy 2023 encompass electronics system design and manufacturing (ESDM), biotechnology and life sciences, food technologies, electric vehicles, aerospace and defence, artificial intelligence/robotics, graphene, and high value-added plantation produce. The State's forward-looking Vision 2031 document (released October 2025) for the industries sector positions these as the foundation for structural reforms aimed at establishing Kerala as India's premier industrial and innovation hub through dedicated corridors, innovation hubs, skill development initiatives, and sustainable ecosystems to accelerate manufacturing growth and private investment. Kerala also has Fertilisers and Chemicals Travancore Limited (FACT), India's largest fertiliser plant with an annual installed capacity of 9.08 lakh MT (The Fertilisers and Chemical Travancore Limited, 2024). This alongside BPCL Kochi Refinery (15.5 MMTPA) is important from decarbonisation perspective (Bharat Petroleum Corporation Limited, 2024).

Energy use in industries occurs on account of fuel/electricity consumption for powering machines and industrial units. Between 2005 and 2021, industrial energy consumption is estimated to have increased from 17.00 PJ to 51.23 PJ. Major fuels consumed in the sector include fuel oil, diesel, and natural gas. Electricity demand in the industrial sector is further expected to grow in alignment with the incentives and support provided under the Industrial Policy 2023.

Table 13: Profile of Major Industrial Entities in Kerala

Industry	Key Entity / Location	Remarks
Petroleum Refining	BPCL Kochi Refinery, Ambalamugal	15.5 MMTPA capacity; products: petrol, diesel, LPG, naphtha, benzene, phenol, ATF, bitumen
Petrochemicals	BPCL IREP+PDPP, Kochi	Propylene derivatives: acrylic acid, oxo-alcohols, acrylates; Rs 20,000 Cr PDPP investment

Industry	Key Entity / Location	Remarks
Fertilisers & Chemicals	FACT Udyogamandal, Ernakulam; FACT Ambalamedu	Ammonia, urea, complex fertilisers (caprolactam, sulphuric acid); BPCL-FACT waste-to-energy MoU
Cement	Malabar Cements, Walayar (Palakkad)	State-owned; capacity ~7 lakh TPA; uses limestone from Palakkad deposits; coal/fuel oil fired kilns
Rubber Processing	Kottayam, Ernakulam, Kozhikode districts	Kerala contributes ~90% of India's NR production; latex, rubber sheets, tyres, foam, gloves
Textiles & Handloom	Kozhikode, Thrissur, Ernakulam	17,000 looms; 15,000+ weavers; spinning mills; coir exports (~60% of global white coir)
Ceramics & Tiles	Thrissur, Ernakulam districts	Floor tiles, sanitary ware; uses local clay; kiln-fired at 1,100–1,300°C
Steel (Mini-mills)	Kochi, Thrissur, Palakkad	Small-scale induction furnace-based re-rolling mills; no integrated blast furnace steel in Kerala
Chemicals	Travancore Titanium Products, Kerala Minerals & Metals	Titanium dioxide, ilmenite, zircon, sillimanite; mineral processing
Shipbuilding	Cochin Shipyard, Kochi	Public sector; builds naval, commercial vessels; annual revenue Rs 2,000+ Cr
Food Processing	Pan-Kerala	Seafood, coconut products, cashew, spices processing

Source: Authors' compilation and analysis

Methodology

To project energy requirements in the industrial sector, a bottom-up approach is used to estimate fuel demand for various industrial processes. Since detailed fuel consumption data for different energy-intensive industries is unavailable, the Annual Survey of Industries (ASI) database (Government of India (A), n.d.) on fuel consumption in monetary terms is referenced. From this, the quantitative value of commodity usage is derived. Based on historical fuel consumption trends, the growth rate of fuel demand is then calculated for future projections. To project future fuel demand, the Kerala State industrial policy and new propositions in the short to medium term are referenced.

Key Insights

Kerala's projected industrial energy demand by 2050 indicates a significant transformation in the State's economic landscape, marked by a shift from traditional industries to emerging technologies like Electric Vehicle (EV) and electronics manufacturing, as well as Green Hydrogen Production. New demand drivers contributing to the rising share of energy demand include advanced rubber products, EV and electronic manufacturing, cement, and processed food products.

Table 14: Industrial sector wise energy demand (PJ) in Kerala

Products	2021	2030	2040	2050
Petroleum Refinery	25.41	26.75	27.02	27.02
Chemical Products	4.62	7.73	9.42	12.06
Food Processing and Food Products	4.09	6.97	10.34	13.89
Cement Production	5.20	6.67	8.96	10.92
Iron and Steel	3.77	6.45	8.67	10.57
Rubber and plastic products	3.86	5.57	6.79	8.69
Textile	1.62	2.41	2.94	3.58
Paper and Paper Products	0.86	1.18	1.44	1.75
Pharmaceuticals	0.31	0.52	0.75	1.08
Wood and Wood products	1.49	2.26	3.08	4.08
EV and Electronic Manufacturing	0.00	2.89	3.78	4.82
Green Hydrogen Manufacturing	0.00	0.00	18.61	24.00

Source: Author's computation based on ASI and PPAC fuel consumption dataset

Petroleum refinery is the largest industrial energy consumer in Kerala at 25.41 PJ in 2021. Its energy demand is projected to plateau at around 27.02 PJ from 2040, indicating industry saturation. In contrast, green hydrogen manufacturing is projected to increase from year 2035 onwards to around 24.00 PJ (200 kt by 2050), building upon the Green Hydrogen Policy 2025 (Draft) that targets 155 kt of green hydrogen production by 2040. Producing this quantity of green hydrogen would require 36.00 PJ of electricity. Food processing is projected to more than triple its energy demand from 4.09 PJ to 13.89 PJ, reflecting a major scale-up of value-added agricultural activities. Substantial growth is also anticipated in the iron and steel, cement, and rubber and plastic products. The emergence of EV and electronic manufacturing as a notable energy consumer further underscores Kerala's transition towards modern, technology-driven industries.

Trends in Energy Demand and Emissions

In 2021, industrial energy demand in Kerala stood at 51.23 PJ. Considering the industrial growth in alignment with the Industrial Policy 2023, it is projected to double to 105.85 PJ in BAU 2050. Electricity is already a significant component of Kerala's industrial energy mix, accounting for 18.70 PJ (36.50%) in the base year. This trend is expected to remain the same even in BAU 2050, even as the electricity driven energy demand rises to 56.84 PJ (53.7%). Natural gas and fuel oil are two other most consumed fuels in the industrial fuel mix, at 13.99 PJ (27.31%) and 9.64 PJ (18.82%) in 2021, with projections for it to increase to 16.59 PJ (15.67%) and 15.05 PJ (14.22%) in BAU 2050. Correspondingly, emissions – which were 2.52 $MtCO_2e$ in 2021 – are expected to rise to 3.96 $MtCO_2e$ in BAU 2050 *(Figure 30)*.

In CN50, total energy demand from the industrial sector would reach 129.03 PJ in 2050. Electrification of heating processes is projected across most industries, with electricity demand reaching 95.27 PJ (73.83%) by 2050, while the share of fossil fuels declines substantially. Green hydrogen – which was absent from the energy mix in 2021, is projected to account for 24.00 PJ (18.60%). As a result, 36.53% of projected emissions could be abated – reaching 2.51 $MtCO_2e$ in 2050.

Despite the shift energy demand in hard-to-abate sectors — cement production, iron and steel petrochemicals, and chemical manufacturing — would continue to be met by refinery fuel gases, fuel oil, natural gas and coal, owing to high-temperature process requirements and the role of hydrocarbons as chemical feedstocks rather than mere energy carriers in refining and steelmaking.

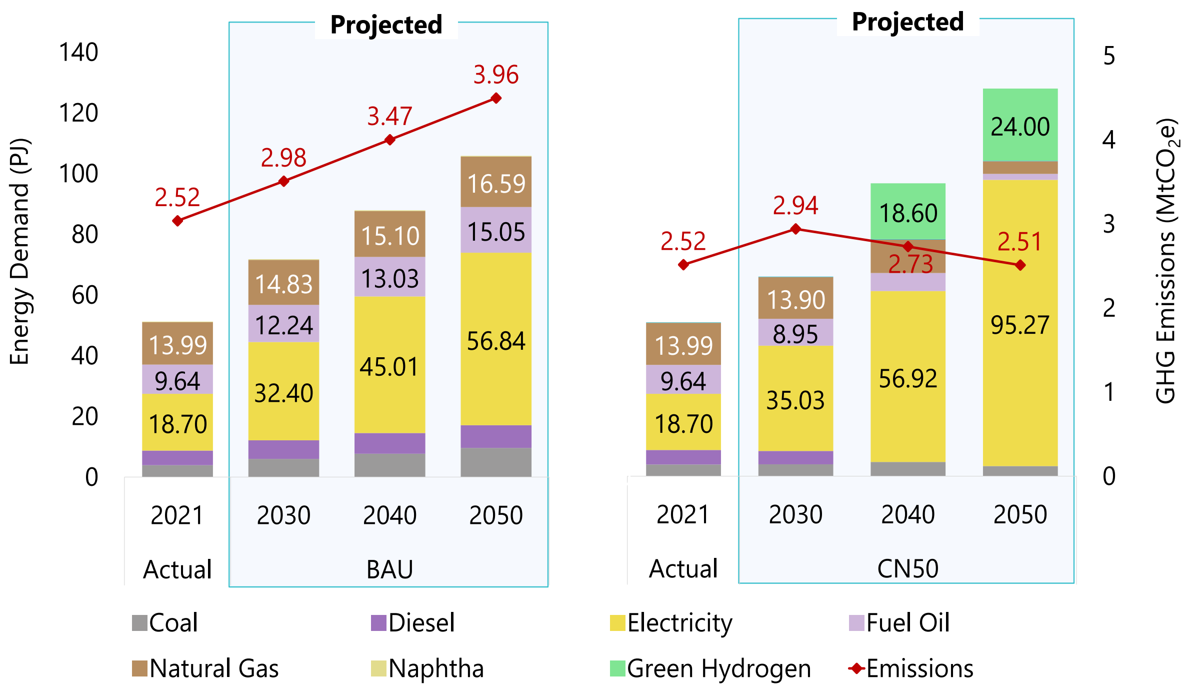


Figure 30: *Fuel-wise Total Primary Energy Supply (PJ) and GHG Emissions ($MtCO_2e$) of Industries in Kerala under BAU and CN50 Scenarios*

Note: In the above stacked diagram, the energy equivalent of electricity is bifurcated into Green Hydrogen demand of 200 TMT (24 PJ) and the remaining electricity (100.21 PJ), including electrolyser efficiency (66.67%), for end-use demand in industrial sectors.

Trends in Electricity Demand

Deep electrification, Industrial modernisation, EV manufacturing growth, and green hydrogen electrolysis are projected to drive incremental electricity demand – from 6.59 TWh in 2021 to 17.19 TWh in BAU 2050, and further to 34.50 TWh in CN50 2050. The projected 200 kt of green hydrogen production in 2050 would add 10.00 TWh of electricity to the total demand. Around 60 kt of this production would serve the electricity needs for fertiliser and petroleum refining alone. *(Figure 31)*.

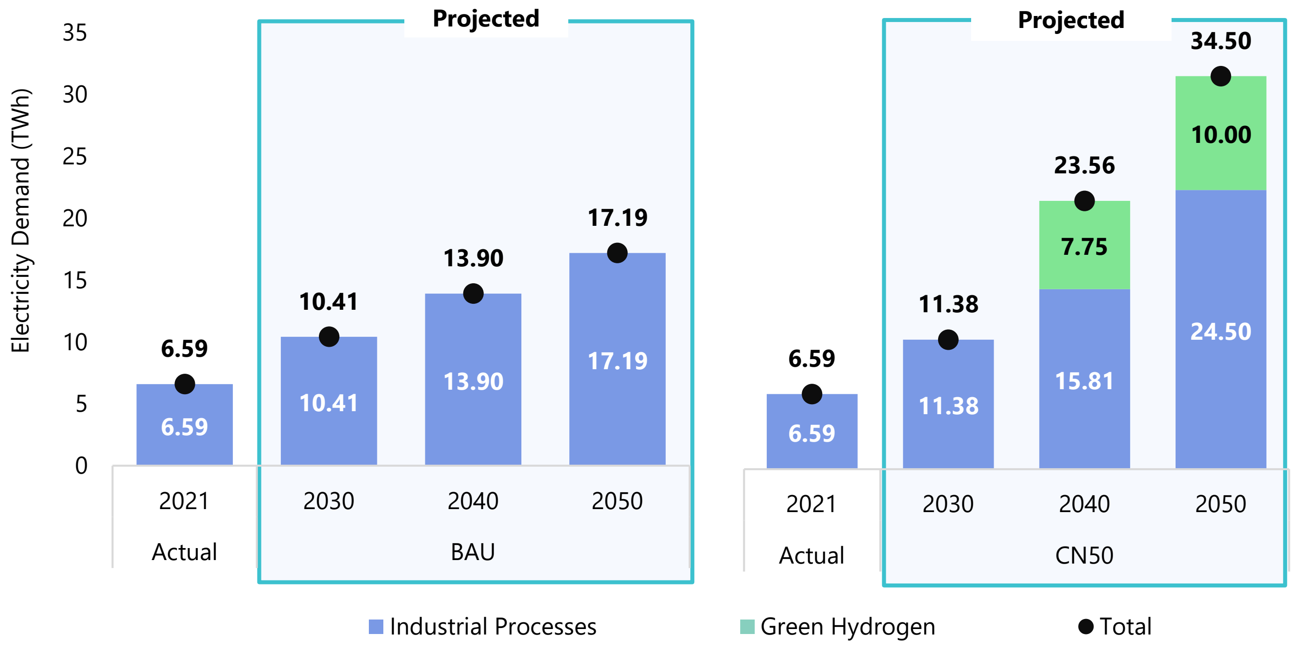


Figure 31: *Electricity Consumption in Industries (including CPP generation) in Kerala, in BAU and CN50*

Note: In the above stacked diagram, electricity demand is bifurcated into Green Hydrogen demand of 200 TMT (10 TWh) and the remaining electricity (24.5 TWh) for end-use demand in industrial sectors, including CPP.

Box Item 11: Current status of Captive Power Plants in Kerala and future outlook under BAU and CN50 Scenario

As of 2021-22, Kerala has a total installed capacity of 592.23 MW across various sources, with gas-fired plants dominating at 201.88 MW, followed by diesel (203.13 MW), coal (86.80 MW), hydro (54.00 MW), and solar (46.42 MW). In the context of electricity generation, the gas plants contributed the largest share at 1051.95 GWh, coal plants generated 170.93 GWh despite their relatively smaller capacity, indicating higher capacity utilisation. Diesel generation remained minimal at 34.15 GWh, suggesting these plants serve primarily as backup power sources.

In the BAU scenario, where the installed capacity remains fixed at 2021–22 level by 2050, CPPs will continue to emit substantial GHGs, particularly from coal and gas usage. Under the CN50 scenario, complete replacement of these fossil fuel-based CPPs with renewable energy sources like solar and wind would eliminate approximately 1,421.28 GWh of fossil fuel-based generation (combining coal, diesel, and gas from 2021-22 data), effectively reducing CPP-related greenhouse gas emissions to zero.

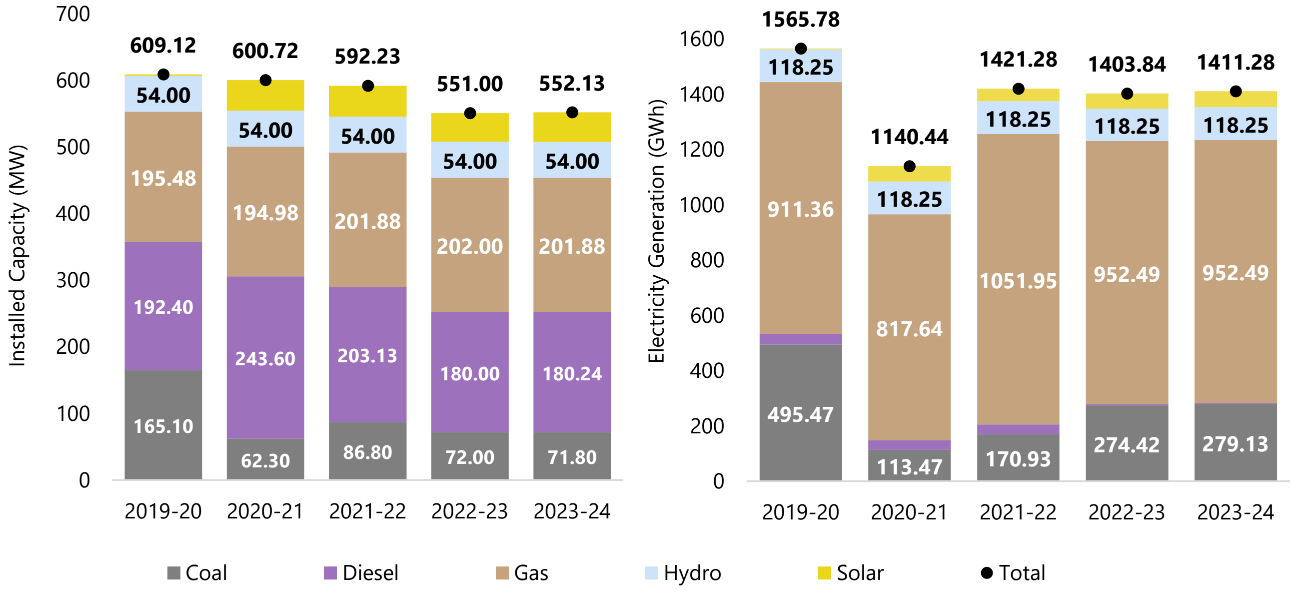


Figure 32: *Total installed capacity (MW) of CPP and Total Electricity generation (GWh), in Kerala*

Replacing fossil fuel-based CPPs with renewables in the CN50 scenario, ~1421.28 GWh of fossil fuel-based generation can be eliminated, reducing CPP-related GHG emissions to zero by 2050.

Key Interventions to Decarbonise Industries in CN50

About 36.53% of projected industrial emissions can be abated by 2050 through,

- Replacement of existing fossil fuel-based heating application with renewable source electric source like green hydrogen-based plasma generators.

0.57 $MtCO_2e$ of Decarbonisation Potential by 2050	**Stakeholders:** Primarily Industries with policy driven support/ incentives, DICs, Private Sector and Technology Providers, Financiers

- Complete replacement of ~491.81 MW fossil-fuel based Captive Power Plants (CPPs) by 2050 either through market-based power procurement (open access or power exchange route) or RE based captive power.

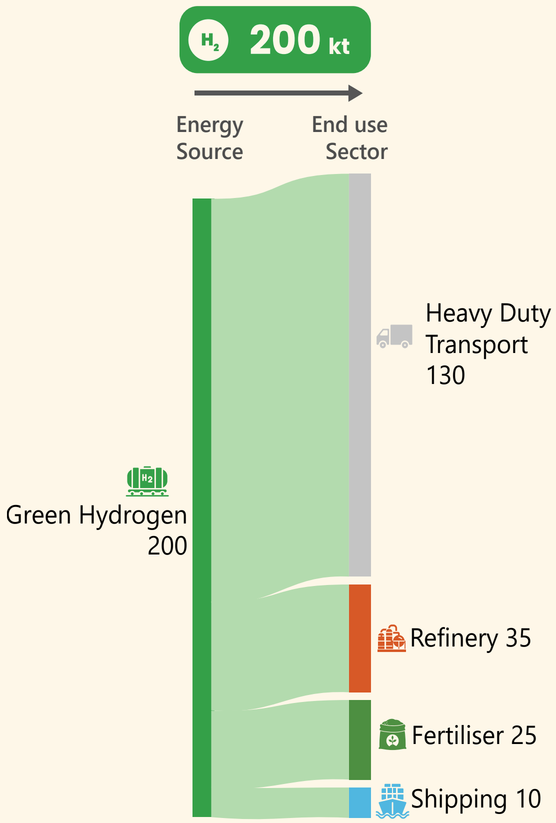
0.67 $MtCO_2e$ of Decarbonisation Potential by 2050	**Stakeholders:** Primarily Industries with policy driven support/ incentives, DICs, Private Sector and Technology Providers, Financiers

- Replacing fossil-based usage with GH_2 in refinery operations can reduce emissions substantially, while also lowering the carbon intensity of refined fuels/fuels produced.

0.21 $MtCO_2e$ of Decarbonisation Potential by 2050	**Stakeholders:** Refinery operators (BPCL Kochi as the anchor), renewable & hydrogen producers, infrastructure providers, regulators, financiers,

Box Item 12: Role of Green Hydrogen in Kerala's Energy Future

Kerala's Green Hydrogen Policy 2025 (Draft) aims to establish the State as India's first fully green-hydrogen-ammonia economy by 2040. It targets harnessing abundant solar, wind, and biomass resources to produce an estimated 155 kt of renewable hydrogen by 2040, with 25% green-hydrogen penetration in hard-to-abate sectors (refineries, fertiliser, chemicals, iron & steel) by 2030 and a 10% blend in city-gas networks. The policy also promotes clean mobility through hydrogen buses, trucks, and waterway vessels, supported by Kochi and Vizhinjam hubs as export gateways for green ammonia and liquid hydrogen under global partnerships. To accelerate such projects, the policy offers a 25% CAPEX subsidy on electrolysers, 10-year waivers on wheeling, transmission and cross-subsidy charges, fast-track open access, and a ₹ 500 Cr land-plus-viability-gap fund to de-risk early 100 MW tranches and integrated H_2/NH_3/CH_3OH plants. Governance is led by ANERT as a nodal agency with a high-level committee, backed by Centres of Excellence and industry-linked skilling programmes.



Green Hydrogen (2050)

Complementing the policy, Kerala is advancing the Hydrogen Valley Innovation Cluster (HVIC). Initiatives include green hydrogen production via electrolysis and biomass, infrastructure for storage/distribution/refuelling, and deployment of hydrogen-powered long-distance buses (KSRTC), city buses (Kochi Metro), boats (Water Transport Department & Kochi Water Metro), and a hydrogen houseboat for eco-tourism. A pilot hydrogen blend in the city-gas network is planned for industrial decarbonisation, while Cochin Port is developing bunkering facilities for shipping. The rollout of Kerala's first hydrogen-fuelled bus marks momentum in road transport.

To support the production of green hydrogen for domestic consumption alone, 7.88 TWh of renewable electricity will be required by 2040. Green hydrogen production is further projected to grow to 200 kt by 2050 – which would increase RE requirement to 10.00 TWh, which could be met by the commissioning of ~0.98-1.26 GW of electrolyser capacity. Given that HVIC has set targets for green hydrogen exports, the electricity requirement could increase to accommodate the growing demand.

Consumption-wise, this analysis projects heavy-duty transport to be the biggest consumer of green hydrogen (65.00% out of 200 kt by 2050), followed by refinery (17.50%), fertilisers (12.50%), and shipping (5.00%).

Aggregate Result of Energy Sector

The section outlines the results on energy supply, electricity consumption and GHG emissions across energy and non-energy uses till 2050, within the overarching scenario framework discussed in the previous subsections.

Total Primary Energy Supply (TPES)

Total Primary Energy Supply (TPES) comprises final energy demand at consumer end along with system-level losses, including resource availability, transformation, and transportation. Figure 33 illustrates TPES projections for the BAU and CN50 scenarios between 2021 and 2050.

In BAU, TPES is projected to rise from 372.34 PJ in 2021 to 648.04 PJ by 2050, representing a 74.04% increase over the period *(Figure 33)*. By 2050, electricity is expected to account for 56.02% of the total energy mix, with fossil fuels comprising the remaining 43.98%. Among all energy sources, electricity records the fastest growth in the BAU scenario (257.98 PJ increase between 2021 and 2050), driven by rising electricity consumption in the building sector, expanding industrial activity, and increasing adoption of EVs. ATF demand grows from 10.54 PJ to 57.90 PJ, reflecting the expansion of both domestic and international passenger aviation.

Conversely, gasoline demand declines even under BAU conditions, primarily due to growing EV penetration in new vehicle sales across two-wheeler, three-wheeler, and four-wheeler segments. Diesel demand in road transport also declines, owing to the rising adoption of electric buses and electric four-wheelers; however, diesel continues to grow in industry and other sectors such as agriculture, water transport, and fishing. Fossil fuel consumption in the industrial sector grows broadly in proportion to overall industrial expansion under the BAU scenario.

In the CN50 scenario, deep decarbonisation across all sectors is achievable through the deployment of available and emerging technologies, with total energy supply reaching 602.75 PJ by 2050. Under this pathway, fossil fuels account for only 17.87% of the total energy mix, with electricity and green hydrogen accounting for the remaining 82.13%, and electricity accounting for 78.14% alone. Compressed Natural Gas (CNG) serves as a bridging fuel in the road transport sector during the transition.

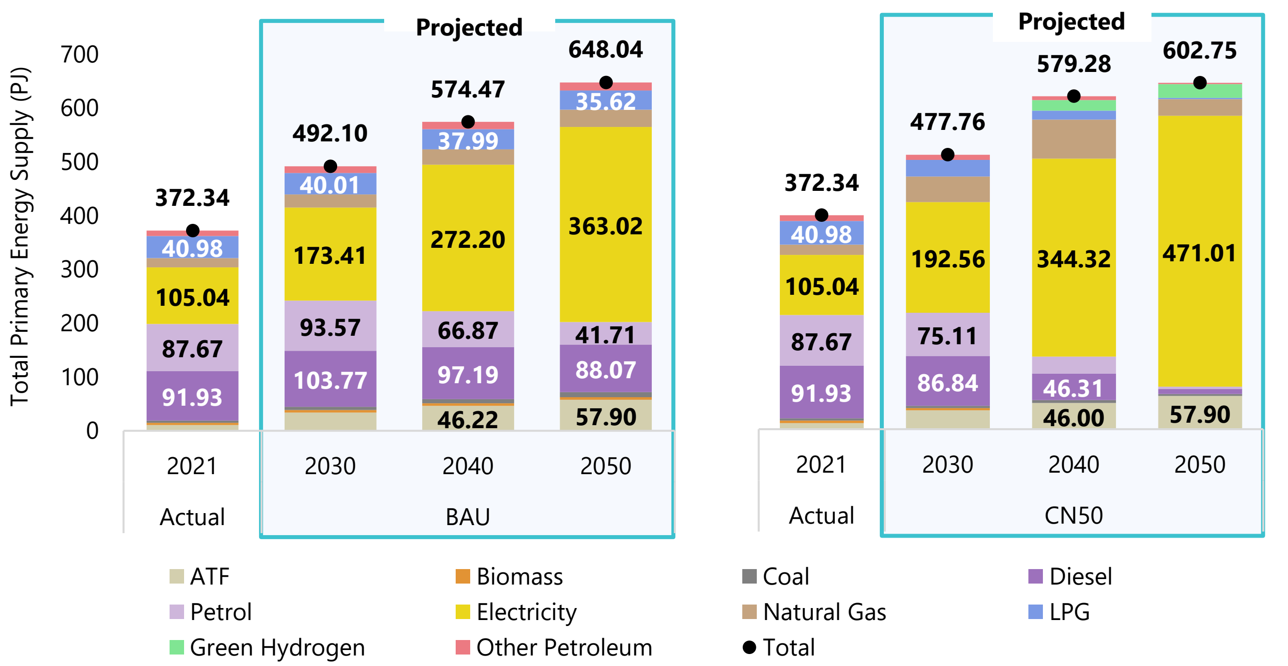


Figure 33: *Primary energy requirement (PJ) by fuel source type*

Deep electrification and energy efficiency initiatives across end use sectors will lead to a ***6.99***% reduction of final energy consumption, making these interventions key drivers of Kerala sustainable energy transition.

Note: Electricity includes T&D losses in the state and end use electricity demand for all years, as well as electrolysis of green hydrogen for year 2040 and 2050 in CN50.

Electricity Demand (TWh)

In the BAU scenario, electricity demand in Kerala – encompassing end-use sector consumption, including captive power plants (CPP) and rooftop solar (RTS) – is projected to grow from 25.84 TWh in 2021 to 92.54 TWh by 2050 *(Figure 34)*. This significant increase is primarily driven by growth in the residential, service, and industrial sectors, coupled with emerging demand drivers such as green hydrogen production, electric vehicle (EV) adoption, and the expansion of data centres. Sustained growth in electricity demand is further supported by rising penetration of space cooling appliances, increasing power requirements for data centres owing to the rapid growth of artificial intelligence and digitalisation, and expanding industrial production.

A substantial share of residential demand growth is attributable to space cooling, which is projected to contribute an additional 26.82 TWh by 2050 under the BAU scenario, after accounting for the offsetting impact of residential rooftop solar systems. In the industrial sector, electricity demand growth is driven primarily by the electrolysis of water for green hydrogen production, with a target output of 200 kt by 2050 requiring approximately 10.00 TWh of electricity.

In the CN50 scenario, the increase in electricity consumption beyond BAU levels is largely attributed to fuel switching across sectors. The transport sector is expected to record the fastest growth, reaching 23.82 TWh (an additional 14.56 TWh over the BAU scenario). The industrial sector follows, accounting for 55.56% of the total incremental electricity demand growth by 2050 relative to BAU. Key sectors driving this growth include green hydrogen manufacturing, food processing, chemical products, and electronics manufacturing.

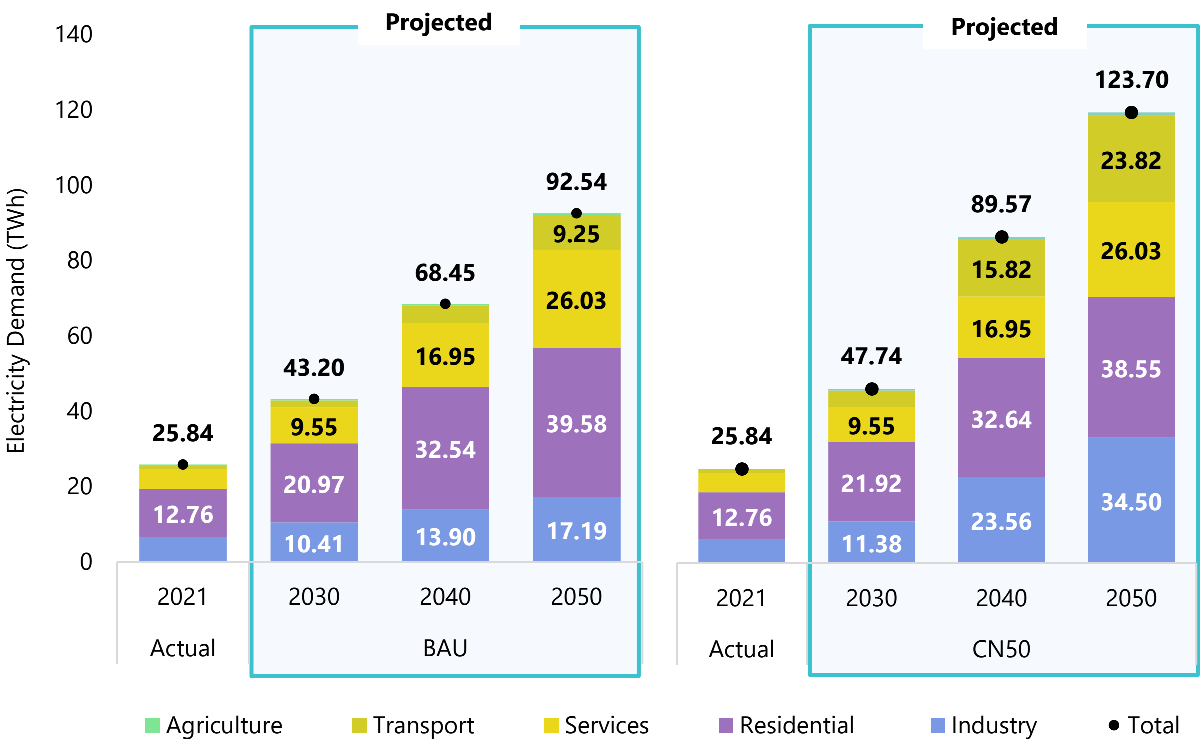


Figure 34: *Electricity demand (in TWh) by energy sector in Kerala*

Electrification across energy sectors would result in a ***33.67***% increase in electricity demand (TWh) in CN50 2050, over and above BAU – reaching 123.73 TWh. Meeting this demand would require generating 134.17 TWh electricity, accounting for 10.47 TWh of T&D losses on grid sourced electricity.

On Grid Electricity Demand (TWh)

Rooftop solar (RTS) plays a crucial role in managing Kerala's on-grid electricity demand by generating power at the source of consumption. This decentralised generation reduces the overall demand on the state's electricity grid, leading to lower T&D losses and increased energy security.

T&D losses are projected to increase in both scenarios due to the overall increase in demand, even as the T&D loss percentage declines due to improved infrastructure. In this, the growth of rooftop solar will play a vital role in mitigating what would otherwise be even higher losses.

Table 15: Projections of Total Electricity Demand (TWh), Rooftop Solar (RTS) Generation, CPP generation, T&D Losses, and Net Grid Demand, under BAU and CN50, in Kerala

Electricity (TWh)	Actual	BAU			CN50		
	2021	2030	2040	2050	2030	2040	2050
Total Electricity Demand (A)	25.84	43.20	68.45	92.54	47.74	89.57	123.70
RTS Generation (B)	0.16	5.18	8.23	9.28	5.18	8.23	9.28
Captive Power Generation (Industry) (C)	1.14	1.40	1.40	1.40	1.40	1.40	1.40
T&D Losses (D)	3.34	4.97	7.16	8.30	5.75	8.62	10.47
Net Grid demand[18] (A-B-C+D)	**27.88**	**41.59**	**66.98**	**90.16**	**46.91**	**88.56**	**123.49**

Energy Sector Emissions

In the BAU scenario, Kerala's GHG emissions from the energy sector are projected to rise 1.18 times by 2050, increasing from 17.35 $MtCO_2e$ in 2021 (excluding public electricity generation) to 20.53 $MtCO_2e$ by 2050 *(Figure 35)*. Majority surge in the GHG emissions from the energy sector include air transport and industry, growing 5.65% and 1.65% annually between 2021 and 2050 respectively. Whereas, in the CN50 scenario, emissions are projected to decline to 9.18 $MtCO_2e$ by 2050 due to fuel switching, particularly through road transport electrification and improvements in the energy efficiency of residential appliances. The reduction in emissions due to fuel switching amounts to 11.35 $MtCO_2e$. A fraction of emissions from the residential sector remains in 2050 due to cooking fuel consumption. Air transport, remaining due to continued use of ATF until a viable substitute is made available, constitutes residual emissions in 2050.

18 This is the net grid demand, calculated as a sum of total electricity demand and T&D Losses, with subtraction of RTS generation and captive power generation. It is also referred to in Chapter 6 of the report.

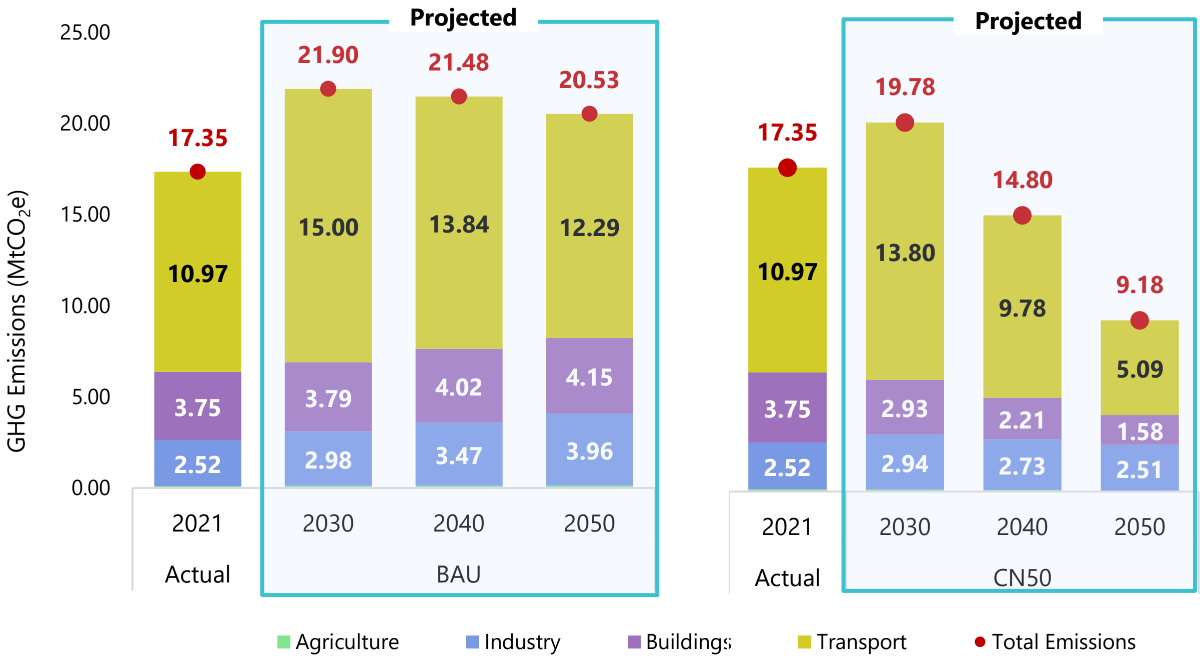


Figure 35: *Sector-wise energy emissions ($MtCO_2e$)*

Note:
- Public Electricity Generation is not included in this estimate. It is discussed in detail in Chapter 6.
- In the BAU scenario, GHG emissions reach a peak in the year 2030 – declining marginally thereafter, majorly due to electrification in road transport. In the CN50 scenario, fuel switching, deep electrification, and the application of green hydrogen reduces emissions to 9.18 $MtCO_2e$ by 2050.

Charging Station for Electric Vehicles, Kerala

Chapter 4

Outlook for Non-Energy Sectors

Key Highlights

The non-energy sector outlook presents projected emissions and emission reduction pathways under the BAU and CN50 scenarios across IPPU, Agriculture, Waste, and LULUCF sectors, highlighting the role of both emissions abatement and enhanced carbon sequestration in achieving carbon neutrality.

Under the BAU scenario

- IPPU emissions are projected to remain constant at 1.32 $MtCO_2e$ through 2050 due to limited adoption of low-carbon alternatives in ammonia production.
- Agriculture sector emissions[19] are projected to increase from 1.56 $MtCO_2e$ in 2021 to 2.07 $MtCO_2e$ by 2050, primarily driven by rising livestock emissions and continued synthetic fertiliser application. Rice cultivation emissions are projected to decline from 186.52 $ktCO_2e$ to 100.04 $ktCO_2e$ due to reduction in cultivated area
- Waste sector emissions are projected to remain nearly stable, increasing marginally from 1.92 $MtCO_2e$ in 2021 to 1.95 $MtCO_2e$ by 2050, with domestic wastewater remaining the dominant contributor.
- The LULUCF sector is projected to continue serving as a major carbon sink, sequestering approximately 14.63 $MtCO_2e$ annually by 2050, primarily through existing forest cover.

Under the CN50 scenario

- In the IPPU sector, complete transition to green hydrogen in ammonia production can abate 0.72 $MtCO_2e$ emissions by 2050.
- Agriculture sector emissions can be reduced by around 16% through balanced rationing, methanogen-suppressing feed additives, manure management through biogas systems, transition towards organic and nano fertilisers, and improved water management practices in rice cultivation.
- In the waste sector[20], enhanced wastewater treatment coverage, faecal sludge

19 Emissions from biomass burning in croplands were negligible and are expected to remain due to declining paddy cultivation and change in cropping patterns in the state. Therefore, no specific interventions are considered under CN50, and BAU emissions are retained as such in the CN50 scenario.

20 The emissions from Solid Waste category have declined between 2005 and 2021 by 59% (113 ktCO2e in 2005 to 46 ktCO2e in 2021) due to its significant efforts in reducing waste generation, source-level segregation, sustained policy focus and grass-level implementation. In view of this, no specific intervention has been proposed under CN50 scenario and BAU emissions are retained as such in the CN50 scenario.

management, and improved industrial effluent treatment systems can reduce projected emissions by nearly 79% by 2050, with domestic wastewater emissions declining from about 1,862 ktCO_2e under BAU to 362 ktCO_2e under CN50.

- Carbon sequestration in the LULUCF sector can be significantly enhanced through increasing forest carbon stock density, expansion of agroforestry and social forestry, and restoration of mangrove ecosystems, increasing total sequestration potential to approximately 23.91 MtCO_2e annually by 2050.

Scenario Assumptions

Assumptions under two different scenarios of BAU and CN50 for non-energy sectors are provided below in Table 16.

Table 16: Assumptions under BAU and CN50 Scenario for Non-Energy Sectors

Sector	Disaggregation	Driver	Scenario-BAU	Scenario-CN50 (over and above BAU)
IPPU	Chemical, Metal and Mineral industry	Annual production	No GH_2 usage	GH_2 usage in fertiliser industry
Agriculture	Agriculture Soils	Increase in net sown area and fertiliser demand to enhance productivity	Current growth	Substituting nitrogen fertiliser and urea with 50% organic fertiliser and 100% enhanced efficiency fertilisers such as nano-urea
	Rice Cultivation	Increase in net sown area	Current growth	Increase in multiple aeration water regime from 43% to 84%
	Livestock	Increase in livestock population	Current growth	90% Balanced rationing, 80% methanogen inhibiting feed additive and 75% manure management
Waste	Domestic Wastewater	Increase in population	Current growth	100% treatment
	Industrial Wastewater	Annual industrial production	Current growth	100% treatment

Sector	Disaggregation	Driver	Scenario-BAU	Scenario-CN50 (over and above BAU)
Carbon Sequestration	-		Existing sequestration to be same till 2050	• Repurposing 75% of the state's 841.16 sq. km of barren, fallow, and wasteland areas (630.87 sq. km) for horticulture, agroforestry, and social forestry. • Enhance the CSD of existing forests • Restoration of 100.60 sq. km of mangroves

1. IPPU

In Kerala, IPPU emissions primarily arise from three sectors: the Chemical Industry (Ammonia, Caprolactam, Carbon Black, Soda Ash, and Titanium Dioxide production), the Metal Industry (Iron and Steel Production), and the Mineral Industry (Cement and Lime Production, Other Uses of Soda Ash), along with Non-Energy Products from Fuels and Solvent Use (Lubricant Use, Paraffin Wax Use). In 2021, these activities together emitted 1.32 $MtCO_2e$ of IPPU emissions, with ammonia production alone accounting for 54.96% of it.

The Fertilisers and Chemicals Travancore Limited (FACT) is India's first large scale fertiliser manufacturing company. It has an annual installed capacity of 6.33 lakh MT of complex fertilizers, 2.25 lakh MT of Ammonium Sulphate and 0.50 lakh MT of Caprolactam (The Fertilisers and Chemical Travancore Limited, 2024). LNG is the basic source of fuel, since the company shifted its operation from Naphtha in 2013-14. It produces ~0.35 million tonnes of ammonia annually for fertilizer production. As natural gas reacts with nitrogen to produce ammonia, it releases CO_2 (~2.5 Kg CO_2/Kg of ammonia), as an industrial process uses emission. Thus, contributed ~0.72 $MtCO_2e$ IPPU sector emissions in 2021.

There is significant potential to mitigate these emissions through the adoption of low-carbon alternatives, such as green hydrogen-based ammonia production and carbon capture and storage. Green ammonia is produced using renewable sources to create hydrogen, which is then combined with nitrogen to form ammonia. This process reduces the carbon emissions associated with traditional ammonia production. Although it is more expensive than grey ammonia, it can achieve cost parity under favourable renewable energy conditions and supportive policies. Similarly, blue ammonia is an intermediate alternative that utilises Carbon Capture, Utilisation, and Storage (CCUS) to minimise the atmospheric release of CO_2 during traditional production processes.

Under the BAU scenario, due to limited application in existing ammonia production plants, this assessment assumes the same level of IPPU emission in future years as well. IPPU emissions, therefore, are expected to remain constant at 1.32 $MtCO_2e$ until 2050. Under the CN50 scenario, it is assumed that from 2040 onwards, 50.00% of the natural gas used in ammonia production (fertiliser industry) will be replaced by green hydrogen, leading to a reduction of 0.36 $MtCO_2e$ in the IPPU sector, and lowering emissions to 0.96 $MtCO_2e$. By 2050, with 100% replacement of natural gas in the fertiliser industry, 0.72 $MtCO_2e$ of GHG emissions can be abated, leaving 0.60 $MtCO_2e$ emissions from the remaining IPPU industries.

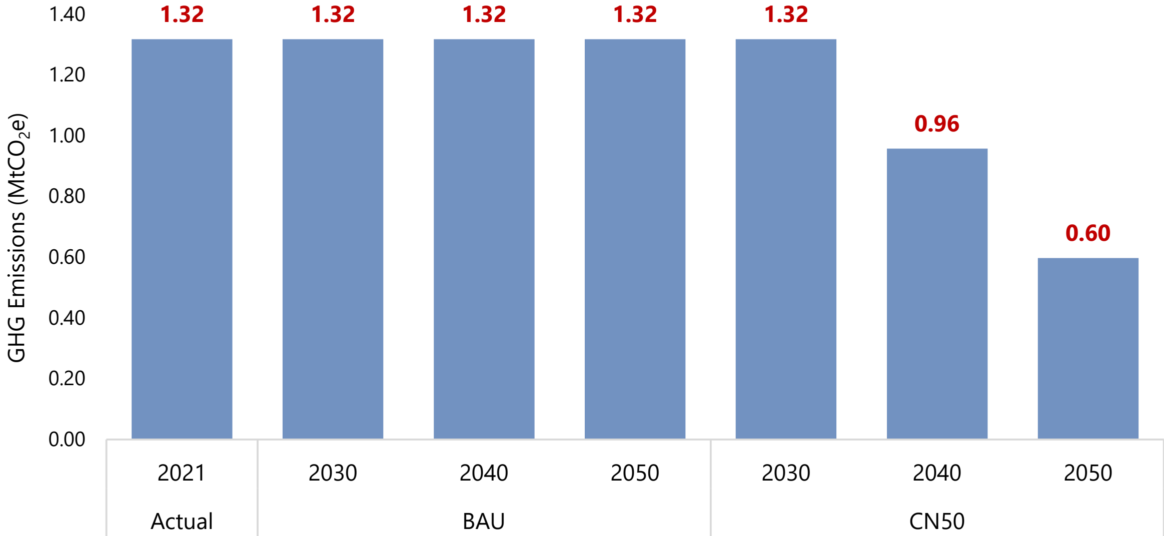


Figure 36: *IPPU Emissions in Kerala*

Switching to green hydrogen (produced through electrolysis powered by renewable energy) for ammonia production can eliminate CO_2 from hydrogen generation. Consequently, green ammonia (using green hydrogen and N_2) is projected to abate 0.72 $MtCO_2e$ of GHG emissions from the fertiliser industry by 2050.

2. Agriculture

Agricultural GHG Emissions account for 7.05% of the total GHG emissions in 2021 (Government of Kerala (C), 2026) as compared to 8.58% in 2005. These emissions emanate from two categories viz- Livestock (Enteric Fermentation and Manure Management - 71.20% in 2021) and Agriculture practices (28.80% in 2021). Emissions from livestock have declined by ~26% compared to 2005 levels, primarily due to a steady decline in the livestock population in the State. The share of agriculture and allied activities in Kerala's GVA has decreased to 9% in 2021-22 from 12% in 2013-14. The State has also witnessed a paradigm shift from food crops towards cash crops, resulting in an increase in the gross cropped area (GCA) for rubber, tea, coffee, cardamom, coconut and cashew, and a significant decrease in GCA for paddy cultivation (Government of Kerala (A), 2023).

In 2021, total emissions from Agriculture activities were 1,564 $ktCO_2e$ and are projected to increase by 32.36% to 2,070 $ktCO_2e$ by 2050, under BAU scenario (Figure 37). Despite the decline in population, livestock remains the prominent emitting categories with a percentage share of ~71% in 2021, followed by, synthetic fertilizer use (~17%) and rice cultivation (~12%) respectively.

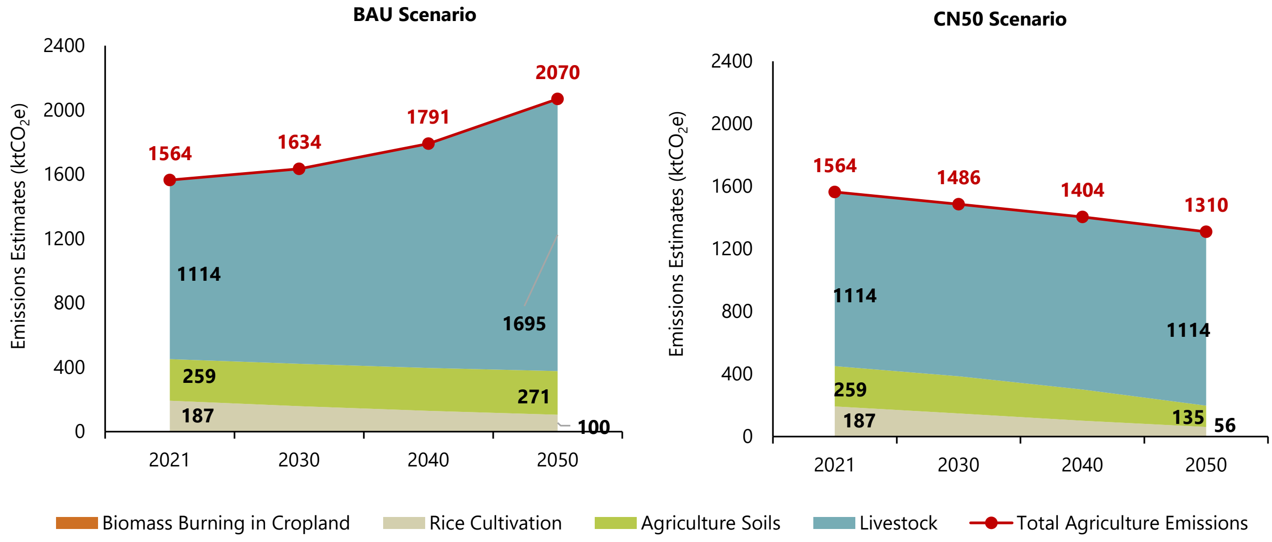


Figure 37: Projected Emissions ($ktCO_2e$) of Agriculture Sector under BAU and CN50 scenario

Note: *Emissions from biomass burning in croplands were negligible and are expected to decline further due to the shift toward cash crops. Therefore, no specific interventions are considered under CN50, and BAU emissions are retained as such in the CN50 scenario.*

2.1 Livestock

The livestock emissions contribute 71% of the agricultural emissions, with enteric fermentation and manure management accounting for ~89% and ~11% of the total livestock emissions respectively. In BAU, GHG emissions from livestock are projected to increase by 52.17% (1,695 $ktCO_2e$) in 2050[21] from 1,114 $ktCO_2e$ in 2021 (Figure 38).

Methodology

Greenhouse gas (GHG) emissions from the livestock sector were projected up to 2050 under two scenarios: Business-as-Usual (BAU) and Carbon Neutrality 2050 (CN50). Under the BAU scenario, emissions were projected using a Compound Annual Growth Rate (CAGR) approach. Historical emission trends were used to estimate future emissions based on expected growth in livestock population and productivity, assuming no major policy or technological interventions.

The CN50 scenario incorporates targeted mitigation interventions aimed at reducing emissions from enteric fermentation and manure management. The following interventions and adoption targets were applied:

- **Methane-Reducing Feed Additives**
  Introduction of **methanogen-suppressing feed inputs** to reduce methane emissions from enteric fermentation: 20% adoption by 2030, 50% adoption by 2040, and 80% adoption by 2050.
- **Balanced Ration Feeding**
  Implementation of **balanced rationing practices** to enhance feed efficiency and reduce enteric emissions: 30% adoption by 2030, 60% adoption by 2040 and 90% adoption by 2050.

21 The livestock population in Kerala has been projected to 2050 using a trend-extrapolation approach based on the observed growth between 2012 and 2019. Historical census data indicate a decline from 34.81 lakh in 2003 to 28.98 lakh in 2012, followed by a recovery to 30.62 lakh in 2019 (citation). The post-2012 period was used to estimate the compound annual growth rate (CAGR), which serves as the basis for forward projections. This approach implicitly assumes continuation of recent recovery dynamics, while incorporating demand-side drivers such as increasing per capita consumption of milk and meat. The projections do not explicitly model structural shifts (e.g., breed composition, productivity changes, or policy interventions), and therefore represent a business-as-usual trajectory conditioned on recent trends.

- **Manure Management via Biogas Plants** Expansion of **biogas-based manure management systems** to reduce methane emissions from anaerobic decomposition: 25% coverage by 2030, 50% coverage by 2040 and 75% coverage by 2050.

Scenario based Projections

Under the Business as Usual (BAU) scenario, the emissions from livestock are projected to increase from 1114 $ktCO_2e$ in 2021 to 1695 $ktCO_2e$ in 2050. Methanogen suppressing feed inputs, balanced rationing and manure management can reduce the GHG emissions from 1695 $ktCO_2e$ in BAU to 1114 $ktCO_2e$ in 2050 (Figure 38). Decadal emissions reduction is detailed in table 17.

Table 17: Projected Emissions ($ktCO_2e$) from livestock under BAU and CN50 scenario

Year	BAU- GHG Emissions ($ktCO_2e$)	CN50- GHG Emissions ($ktCO_2e$)
2021	1114	
2030	1213	1102
2040	1396	1104
2050	1695	1114

Interventions

- Use of improved feed supplements[22] for suppressing methanogens
- Promote better/efficient manure management practices, like biogas production from cattle manure by endorsing the GOBAR-Dhan scheme[23].
- Encourage and subsidise cattle farming with advanced feed and manure management.
- Training and promotion of balanced rationing, such as the Ration Balancing Programme[24]- initiative of National Dairy Development Board
- Promote aerobic management of cattle manure such as composting or direct application to the soil.

22 **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% (National Institute of Animal Nutrition and Physiology, n.d.).

23 **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 (Government of India (B), n.d.).

24 **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 (Government of India (G), n.d.).

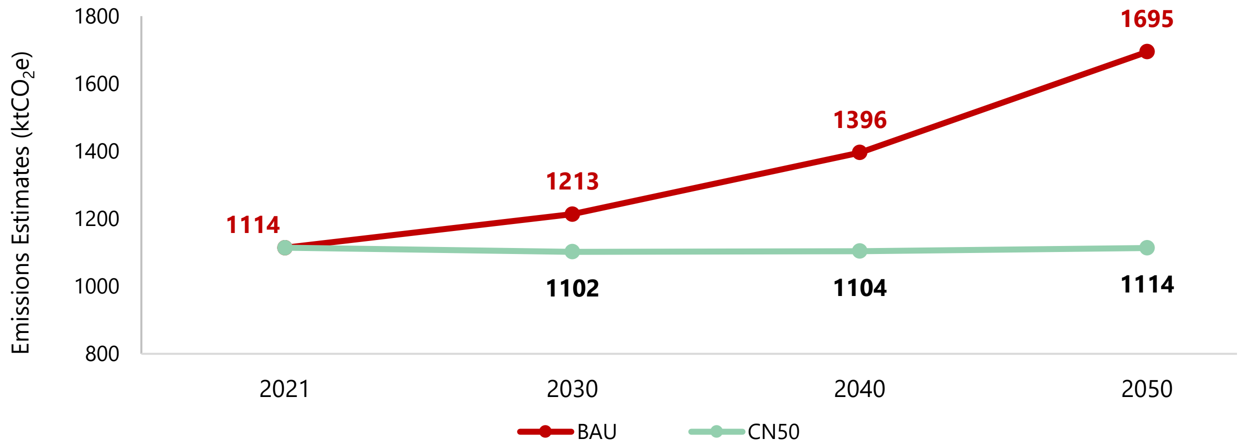


Figure 38: *Projected Emissions (ktCO_2e) from Livestock under BAU and CN50 scenarios*

Box Item 13: Ongoing initiatives to enhance dairy productivity which has a default co-benefit of methane emissions reduction (Government of India (G), n.d.) (Malabar Rural Development Foundation, n.d.)

MILMA (Kerala Co-operative Milk Marketing Federation) serves as the backbone of the State's dairy sector, supporting a vast network of farmer cooperatives. MILMA has recently undertaken initiatives to reduce methane emissions from enteric fermentation, while improving farmer livelihoods includes:

- **Ration Balancing Program (RBP):** Improved milk quality and reduction in enteric methane emissions by approx. 13.7% per kilogram of milk is achieved through optimized diets. These diets ensure precise nutrient intake using locally available feed resources.
- **Biogas & Waste Management:** ₹25,000 subsidy for on-farm biogas plants.
- **Subsidized Feed Additives:** Distribution of algal-based buffers and mineral mixtures to improve rumen fermentation which helps the digestive system, lowering methane production during natural fermentation.
- **Fodder Hubs & Quality Roughage:** By supplying high-quality silage and maize fodder, MILMA ensures cows digest feed more efficiently. Higher-quality roughage results in less waste and lower methane output.
- **Capacity Building:** Awareness programs for farmers on improved feeding and livestock management practices.

2.2 Agriculture Soils

Emissions from agriculture soils are due to application of Nitrogen based synthetic fertilisers. In 2021, Agriculture soils emissions contributed 17% of the agricultural emissions and accounted for 258.89 ktCO_2e.

Methodology

Emissions from agricultural soils are estimated based on nitrogen and urea consumption, and the emissions are projected under BAU and CN50 scenarios. In the BAU scenario, nitrogen and urea consumption are projected using the Compounded Annual Growth Rate (CAGR) method. Under this scenario, emissions from synthetic fertiliser consumption are expected to increase by 4.50% over the period from 2021 to 2050. The CN50 scenario aims for substitution/ replacement of synthetic fertilisers with organic/ natural fertilisers and enhanced efficiency fertilisers such as nano urea[25]. By 2050, 50% of synthetic nitrogen fertiliser demand is projected to be substituted through organic fertilisers and the remaining urea requirement will be met through enhanced efficiency fertilisers such as nano urea. The decadal transition plan for fertiliser substitution is outlined in Table 18.

Table 18: Transition plan for fertiliser substitution

Year	Organic fertiliser substituted for total nitrogen and urea	Enhanced efficiency fertilisers such as nano urea substituted for urea
2030	10%	25%
2040	25%	75%
2050	50%	100%

Scenario based Projections

Under the BAU scenario, nitrogen consumption is projected to increase from 85.99 kt in 2021 to 89.86 kt in 2050, while Urea consumption from 129.29 kt in 2021 to 137.07 kt in 2050. The increase in synthetic fertiliser consumption is expected to raise GHG emissions from agriculture soils from 258.89 ktCO_2e in 2021 to 270.53 ktCO_2e by 2050 (Figure 39). In the CN50 scenario, significant shifts in the fertilizer consumption with organic fertilizer and enhanced efficiency fertilisers such nano-urea are anticipated to decrease emissions from agriculture soils by 50% the projected 270.53 ktCO_2e in BAU to 135.27 ktCO_2e in 2050. Detailed decadal emission reductions are provided in table 19.

Table 19: Projected emissions (ktCO_2e) from Agriculture Soils under BAU and CN50 scenario

Year	BAU- GHG Emissions (ktCO_2e)	CN50- GHG Emissions (ktCO_2e)
2021	258.89	
2030	262.45	236.20
2040	266.46	199.84
2050	270.53	135.27

Consistent with Kerala's Agriculture Development Policy (2015), the State recommends the large-scale promotion of bio-manure and bio-fertilisers. Natural farming techniques, such as using residues for coconut plantations and establishing closed-farm systems for vegetable cultivation, are critical strategies for promoting more sustainable and resource efficient nutrient management (P., Gupta, V, Bhat, & Bhat) (Das & Mishra, 2026).

25 Nano Urea is a nanotechnology based Agri-input which provides nitrogen to plants. When compared to conventional urea prill, it has a desirable particle size of about 20-50 nm and more surface area and number of particles. Nano fertilizer has the potential to regulate the release of nitrogen (N) for an extended period (20 days) in comparison to the conventional urea fertilizer (9 days). The slow and steady release of nitrogen through nano-fertilisers has the potential to significantly reduce nitrous oxide emissions from fertilised soils (Jagatheesan, Subramanian, & Lakshmanan, 2019)

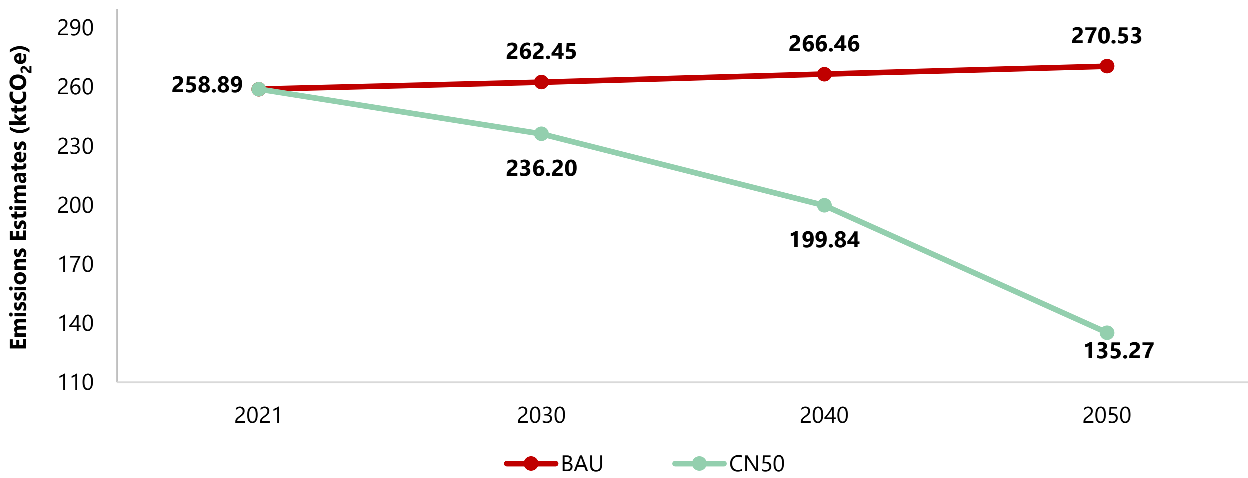


Figure 39: *Projected Emissions ($ktCO_2e$) from Agriculture soils under BAU and CN50 scenarios*

The decarbonisation pathway assumes a gradual transition away from conventional urea toward more nitrogen-efficient nutrient management systems by 2050, aimed at reducing emissions from agricultural soils while maintaining crop productivity.

The transition begins with partial substitution through nano-fertilisers and biogenic inputs (e.g., bio-inoculants, manure, vermicompost), supported by improved nutrient management practices. Adoption is expected to scale as technologies mature and costs decline. Reducing urea dependence is critical in India due to its energy-intensive production and high subsidy burden. Improving nitrogen use efficiency (NUE) can therefore reduce nitrous oxide emissions, lower upstream production emissions, and ease fiscal pressure.

Complementary measures include:

- **Precision application:** Drip fertigation in high-value crops to improve nutrient and water use efficiency.
- **Integrated nutrient management:** Use of INM practices and decision-support tools (e.g., GreenSeeker, Nutrient Expert) to optimise fertiliser use.
- **Soil health improvement:** Application of organic amendments (e.g., compost, manure, coir-based inputs) to enhance soil structure, microbial activity, and nutrient cycling.
- **Soil moisture management:** Mulching and improved aeration to improve water retention, reduce salinity impacts, and support soil function.

Box Item 14: Soil Organic Carbon (SOC) Sequestration

As part of the agricultural soils decarbonisation pathway, enhancing **Soil Organic Carbon** (SOC) through organic mulching is a key complementary intervention. By converting biomass into stable carbon pools, mulching enables long-term sequestration of atmospheric CO_2 while improving soil moisture retention and resilience to drought.

This intervention is particularly relevant in Kerala, where despite relatively higher baseline SOC levels (Adilakshmi, et al., 2023), tropical temperatures and monsoon-driven erosion accelerate carbon loss (Jaya et. al., 2026) (Government of Kerala, 2018). Organic mulching helps stabilize carbon within the soil, improving aggregation and reducing bulk density. This supports better root growth, nutrient availability, and water dynamics, including higher infiltration and sustained soil moisture during dry periods (Rossi, Beni, & Neri, 2024). Together, these outcomes contribute to both mitigation (carbon storage) and adaptation (soil and water resilience).

Importantly, SOC enhancement through mulching complements nitrogen management strategies by reducing soil emissions, improving input efficiency, and strengthening long-term climate resilience.

The Bharatiya Prakritik Krishi Padhathi (BPKP) positions organic mulching as a core regenerative practice to restore soil health and strengthen climate resilience. The scheme focuses on recycling on-farm biomass into stable carbon pools. It combines financial incentives and system-level support to make mulching both adoptable and economically viable for farmers (Government of Kerala (A), 2021).

- **Incentives for adoption and practice:** ₹1,600/ha supports the labour required for mulching, while a ₹2,000 incentive encourages the continuation of indigenous, self-mulching multi-tier cropping systems.
- **Infrastructure and demonstrated impact:** ₹7,500 support for input production units enables conversion of residues like coconut husks into mulch backed by a total allocation of ₹4,455.36 lakhs (Central and State share under the Centrally Sponsored Scheme), while ₹2,400 for demonstration plots validating outcomes such as 70–80% weed suppression and up to 50% reduction in irrigation needs.

2.3 Rice Cultivation

Paddy fields are a significant source of methane emissions in the agriculture sector, arising from the anaerobic decomposition of organic matter in flooded paddy fields. Emissions from rice cultivation were estimated at 186.52 ktCO_2e in 2021, contributing 12% of the State's total agriculture sector emissions.

Methodology

Currently, Kerala utilises three primary water regimes for rice cultivation; intermittent single aeration (ISA, ~56%), intermittent multiple aeration (IMA, ~43%) and upland (0.54%).[26] Emissions from Rice Cultivation are expected to decrease in 2050 under the BAU as a result of shrinking area under rice cultivation. Under CN50, by promoting intermittent multiple aeration practice over intermittent single aeration[27] across 75% of the area under paddy cultivation, can further reduce the emissions. Decadal water regime transition plan is described in Table 20.

Table 20: Decadal water regime transition plan

Year	Single Aeration	Multiple Aeration	Upland
2030	49.63%	49.83%	0.54%
2040	34.68%	64.77%	0.54%
2050	15.25%	84.21%	0.54%

26 Single aeration can be defined as fields that have a single aeration during the cropping season at any growth stage; Multiple aeration can be defined as fields that have more than one aeration period during the cropping season; Upland can be defined as fields that are never flooded for a significant period of time (IPCC)

27 The emission factor for intermittent single aeration is 66 kg CH_4/Ha and intermittent multiple aeration is 18 kg CH_4/Ha (Pathak, et al. (2010).

Scenario Based Projections

In the BAU scenario, emissions from rice cultivation are projected to decline from 186.52 ktCO_2e in 2021 to 100.04 ktCO_2e by 2050. Transitioning the water regime shift from intermittent single aeration to intermittent multiple aeration can reduce the GHG emissions from rice cultivation by 43.76% from 100.04 ktCO_2e in BAU to 56.26 ktCO_2e in CN50 (Figure 40). Decadal emissions reduction is detailed in Table 21.

Table 21: Projected Emissions (ktCO_2e) from Rice Cultivation under BAU and CN50 scenario

Year	BAU- GHG Emissions (ktCO_2e)	CN50- GHG Emissions (ktCO_2e)
2021	186.52	
2030	153.73	143.03
2040	124.01	95.54
2050	100.04	56.26

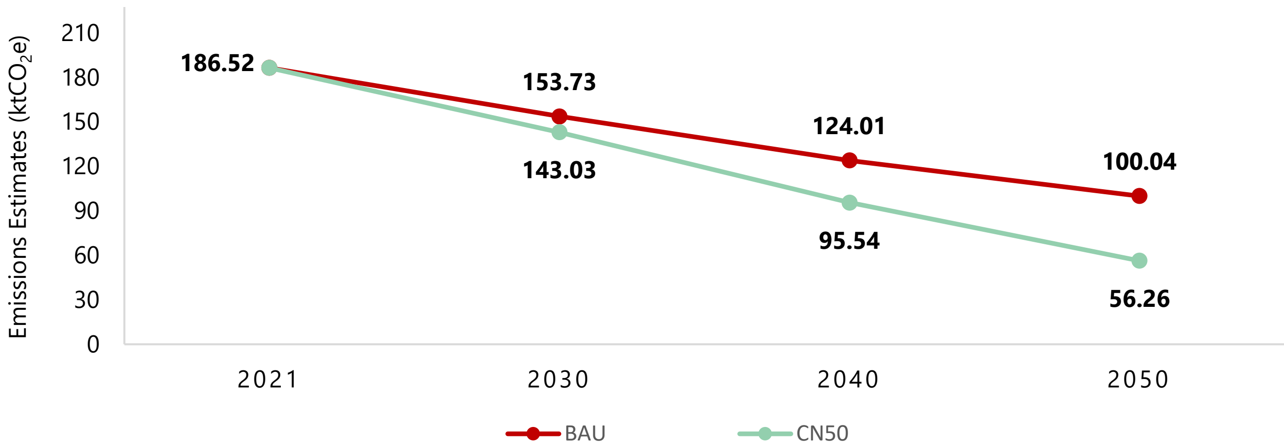


Figure 40: *Projected Emissions (ktCO_2e) from Rice Cultivation under BAU and CN50 scenarios*

Box Item 15: Climate-Smart Rice cultivation: The KERA-AWD Initiative

The Kerala Climate Resilient Agri-Value Chain Modernization (KERA) initiative is a climate-resilient agriculture project focusing on low-emission rice production in the paddy clusters of Thrissur and Palakkad regions. It utilizes Alternate Wetting and Drying (AWD), a water management technique that involves controlled irrigation cycles to reduce greenhouse gas emissions. By installing field sensors to monitor water levels in real-time, the project allows farmers to transition away from the traditional continuous flooding method while maintaining crop productivity (AWD, 2026).

- **Objectives:** The project's primary goal is to establish a robust Monitoring, Reporting, and Verification (MRV) system to generate high-accuracy emission data. By validating a reduction of 2,760 kg CO_2e per hectare annually, the initiative aims to achieve a total yearly reduction of over 55,000 tonnes of CO_2e across the 20,000-hectare project landscape (Government of Kerala (C), 2023).
- **Implementation**: The project has identified 17 pilot paddy clusters and conducted station-level trials at Mannuthy and Pattambi. The next phase involves a significant expansion to cover around 20,000 hectares, directly benefiting 45,000 farmers across the region.

Box Item 16: Per Drop More Crop (PDMC): Scaling Micro-Irrigation in Kerala (Indian Institute of Management, Ahmedabad, 2021) (Government of India (D), 2021)

The Per Drop More Crop (PDMC) scheme, a core component of the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), focuses on enhancing water-use efficiency through precision micro-irrigation. The scheme helps Kerala's farmers transition from traditional flooding to targeted delivery through drip and sprinkler systems.

- **Water Efficiency & Productivity:** Micro-irrigation essentially halves the water burden on the farm. Recent study validates a 50% reduction in water pumping hours across the board. While water use drops, production typically increased by an average of 73%, with commercial staples like bananas seeing gains as high as 216%. While sprinklers are ideal for quick field crops, drip systems are preferred for long-term commercial plantations.
- **Targeted Financial Support:** Small and marginal farmers can receive up to 85% financial assistance, while other farmers are eligible for a 45% baseline subsidy.
- **The Economic Benefits:** The scheme slashes the primary costs of farming electricity, labor, and maintenance. Electricity costs for pumping drop by 11% and the specific labor required for irrigation is significantly reduced. Precision delivery also keeps inter-row spaces dry, resulting in fewer weed problems and reduced soil erosion.
- As per the latest monitoring data (2023–24), a cumulative 6,301.6 hectares have been brought under the scheme across the State (Government of India (E), n.d.).

PDMC directly supports Kerala's net-zero goals by shrinking the energy footprint of agricultural pumping.

3. Waste

The waste sector plays a critical role in Kerala's overall greenhouse gas (GHG) emissions profile and represents a significant opportunity for targeted climate action. As of 2021, the sector was the second-highest contributor to economy-wide emissions, accounting for approximately 8.66% of the State's total gross emissions. A breakdown of emissions within the sector reveals that domestic wastewater is the dominant source, contributing nearly 95.53% of waste sector emissions. This is followed by solid waste management, contributing at around 2.39%, and industrial wastewater which contributes approximately 2.08% (Government of Kerala (C), 2026).

Under the BAU scenario, emissions from the waste sector are projected at approximately 1948 ktCO_2e by 2050, remaining broadly in the same range as the 2021 level (~1921 ktCO_2e) as shown in Figure 41. Strengthening waste treatment and emission mitigation measures is therefore essential to address growing waste volumes and reduce associated environmental and climate impacts.

Kerala has made notable strides in solid waste management. Since 2017, the State has progressively adopted a zero-landfill approach, minimising the disposal of municipal solid waste in landfills through source segregation, decentralised treatment, and resource recovery initiatives (Based on inputs received from KSPCB). This shift reflects Kerala's commitment to environmentally responsible waste handling, marked by high rates of source segregation, decentralised treatment systems, and active community participation through initiatives like the Haritha Karma Sena. This section thus focuses on interventions for reducing emissions from the domestic wastewater and industrial wastewater category, which together constitute the largest contributors to GHG emissions within the waste sector.

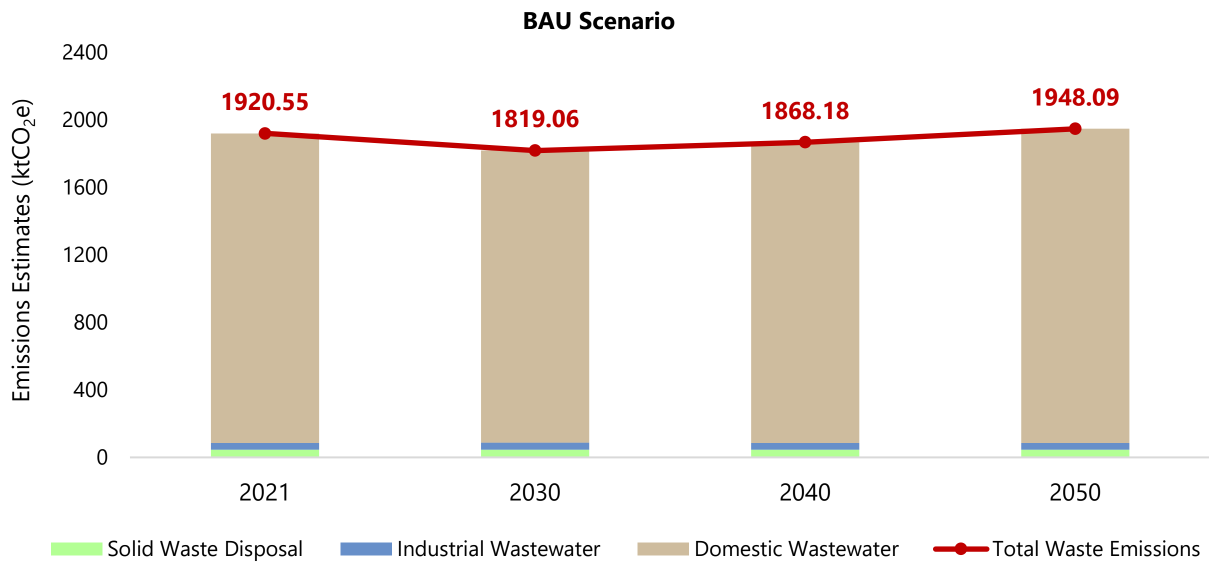


Figure 41: *Projected Emissions ($ktCO_2e$) of Waste sector in BAU scenario, Kerala*

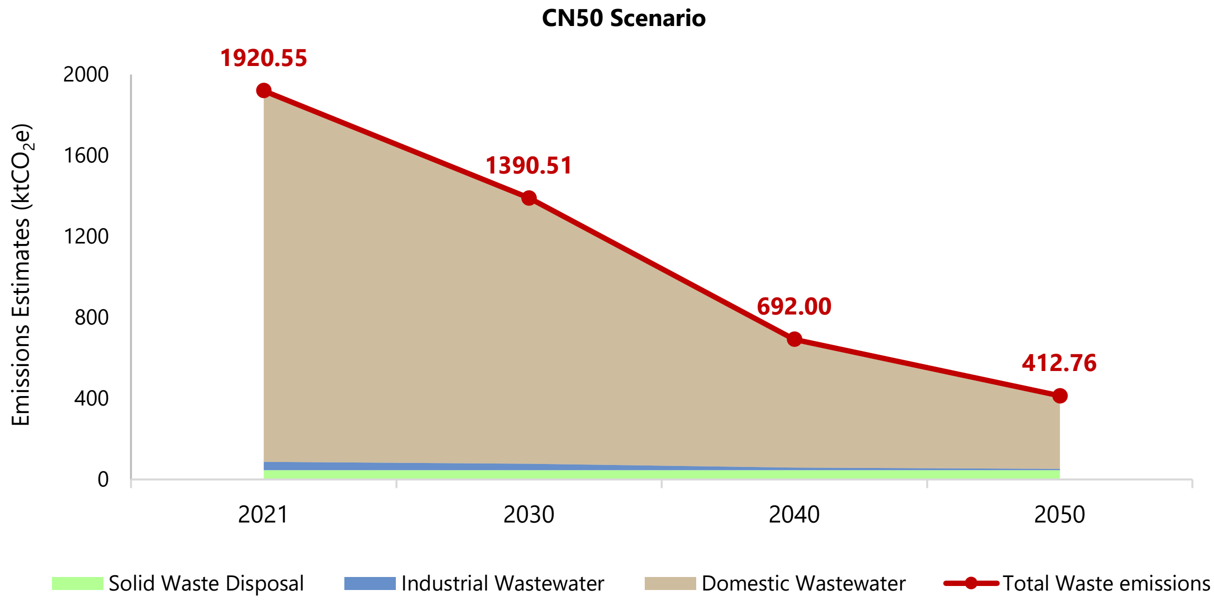


Figure 42: *Projected Emissions ($ktCO_2e$) of Waste sector, in CN50 scenario, Kerala*

3.1 Domestic Wastewater

Domestic Wastewater with total emissions of 1834.63 $ktCO_2e$ constitutes 95.53% of Kerala's total Waste Sector emissions, and ~7% of the State's gross emissions in 2021. 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 projected to reach 1,861.8 $ktCO_2e$ by 2050 under the BAU, resulting from 4379 Million Litres per Day (MLD) wastewater generation. As of January 2025, the centralised wastewater treatment capacity, including operational, under construction and proposed facilities stands at 387 MLD (KSPCB, 2025).

Methodology

The projection of greenhouse gas (GHG) emissions from domestic wastewater treatment in Kerala was carried out up to the year 2050. The estimation methodology was grounded in projected population data and the current and planned wastewater treatment infrastructure, including operational, under-construction, and proposed Sewage Treatment Plants (STPs).

Wastewater Generation Estimation:

Total domestic wastewater generation was estimated by multiplying the projected population with a per capita wastewater generation rate of 112 litres per person per day (Government of India (C), 2023). This formed the basis for determining the annual wastewater load requiring treatment. However, for GHG estimation, the annual organically degradable carbon load was determined using a per capita BOD rate of 40.5 g/person/day, adjusted by a correction factor (I) of 1.25 for collected systems to account for co-discharged industrial/commercial BOD.

Treatment Capacity and Scenario Development:

For each projection year, the existing treatment capacity—including operational, under-construction, and proposed STPs—was considered. Under the CN50 scenario, progressive targets were set to increase wastewater treatment coverage, aiming to treat 30% of total wastewater generated by 2030, 80% by 2040, and 100% by 2050. Under the CN50 scenario, treatment coverage includes both centralised sewage treatment systems and decentralised septic tank systems integrated with faecal sludge treatment facilities. These scenario targets were aligned with anticipated infrastructure development.

Annual Emissions Estimation:

Based on IPCC guidelines and performance assumptions (BOD removal efficiency), appropriate emission factors were applied to each treatment pathway. GHG emissions were calculated by applying these emission factors to volumes of untreated and partially treated wastewater.

A range of approaches with combinations of offsite and onsite treatment were explored for the State, as detailed in Box-item 17. Onsite wastewater treatment is preferred in the State due to limited land availability, dense population, narrow roads, sewer lying constraints related to natural gradients, and high land-cost (Government of Kerala (F), 2022).. Accordingly Approach–3, detailed in Box-Item 17 was adopted. For other Municipalities and Grama Panchayats (GPs), household level septic tanks (adhering to guidelines by Vasuki and Suchitwa Mission (n.d.) coupled with Faecal Sludge Treatment Plants (FSTPs) at the GP cluster level are suggested.

The CN50 scenarios were developed based on the assumption of 40% BOD removal efficiency for standalone septic tanks and 85% BOD removal efficiency for septic tanks integrated with FSTP for the treatment of accumulated sludge. Residual greenhouse gas emissions are expected from wastewater treatment processes even under high treatment coverage scenarios.

Scenario Based Projections[28]

The GHG emissions from domestic wastewater management are estimated to reach 1,861.8 ktCO_2e by 2050 under BAU, resulting from a projected generation of 4379 Million Litres per Day (MLD). The initial decline in BAU emissions despite increasing wastewater generation reflects the inclusion of operational, under-construction, and proposed treatment infrastructure already planned under existing policies and programmes. Year on year wastewater generation and the associated GHG emissions under the BAU and CN50 scenarios are detailed in Table 22.

Table 22: Scenario-based projection of Domestic Wastewater

Year	Wastewater Generation (MLD)	BAU GHG Emissions (ktCO_2e)	CN50 GHG Emissions (ktCO_2e)
2021	3975	1834.63	
2030	4099	1731.89	1314.14
2040	4206	1781.44	633.74
2050	4379	1861.80	361.66

Interventions

To achieve effective wastewater management and recycling by 2050, an additional treatment capacity of ~4391 MLD (including a 10% safety buffer) is required. Approach–3, detailed in Box-Item 17 was considered and it recommends centralised aerobic treatment of ~194MLD using activated sludge process along with sludge treatment, in addition to the operationalization of the proposed STPs, for densely populated cities Centralised treatment systems supported by a hybrid model that uses truck-based faecal sludge collection and treatment to serve areas beyond sewered networks, are recommended for these high population cities to address terrain constraints, avoid the risk of poor construction, inadequate operation, and maintenance that often lead to ground and surface water contamination. A comparison of onsite and offsite treatment options is described in Annexure 2.

For other Municipalities and Grama Panchayats (GPs), the strategy relies on septic tanks (adhering to guidelines by Vasuki and Suchitwa Mission (n.d.)) at the household level, supported

Box Item 17: A comparison of different approaches considered for wastewater treatment in Kerala

Five alternative strategies were evaluated to enhance wastewater management in Kerala. These approaches vary based on population density thresholds, geographic focus, and infrastructure type, ranging from comprehensive sewer networks with STPs in high-density areas to decentralized systems like septic tanks, with or without FSTPs, in less dense regions. The options also consider strengthening existing infrastructure and prioritizing key urban centers. After evaluating the feasibility, cost-effectiveness, and implementation potential of each option, **Approach 3** has been selected for its balanced focus on urban infrastructure development and decentralized solutions for less dense areas.

28 BAU industrial wastewater emissions were projected using a CAGR approach based on 2019–2023 wastewater generation trends from the Kerala GHG Inventory (Version 2). Despite emissions increasing between 2021-23, the overall period reflects a slight decline from 2019 levels. Therefore, there is a marginally negative CAGR and lower BAU projections.

by a network of Faecal Sludge Treatment Plant (FSTP) systems at the GP cluster level. This strategy is expected to reduce emissions by 81%, from 1861.80 ktCO_2e under the BAU scenario to 361.66 ktCO_2e under the CN50 scenario.

Approach	Description	GHG emissions avoided	Additional treatment required [29]	Action points
Approach 1	Setting up of sewer network and STP for all areas of Kerala with a population density above 1500 /km^2 And septic tank + FSTP for other regions	86%	• 614 MLD centralized treatment • 157 FSTPs of 8.2 KLD capacity each to treat the sludge resulting from 3511 MLD wastewater treated with septic tanks	For the 70 high population city/towns: • Ensure 100% Underground Drainage (UGD) connection • Install STP of 614 MLD capacity For other regions: • Promote septic tank-based treatment, adhering to the guidelines. • Install 157 FSTPs for faecal sludge treatment • Efficient deployment of desludging vehicles to transport the sludge from household septic tanks to the FSTP
Approach 2	Setting up of a sewer network and STP for all areas of Kerala with a population density above 3000 people per km^2 and septic tank +FSTP for the other regions	85.6%	298 MLD centralized treatment + 171 FSTPs of 8.2 KLD capacity each to treat the sludge resulting from 3826 MLD wastewater treated with septic tanks.	For the 25 high population city/towns: • Ensure 100% UGD connection • Install STP of 298 MLD For other regions: • Promote septic tank based treatment, adhering to the guidelines • Install 171 FSTPs for faecal sludge treatment • Efficient deployment of desludging vehicles to transport the sludge from household septic tanks to the FSTP

29 In addition to efficient operation of 387 MLD of installed, under construction and proposed STPs as on January 2025 (Government of India (B), May 2022)

Approach	Description	GHG emissions avoided	Additional treatment required [30]	Action points
Approach 3	Setting up of a sewer network and STP for densely populated cities of Kerala, along with hybrid model that uses truck-based faecal sludge collection and treatment to serve areas beyond sewered networks And septic tank +FSTP for the other regions	81%	194 MLD centralized treatment along with sludge treatment + 176 FSTPs of 8.2 KLD capacity each to treat the sludge resulting from 3953 MLD wastewater treated with septic tanks	For the densely populated cities/towns: • Ensure 100% UGD connection • Install STP of 194 MLD For other regions: • Promote septic tank-based treatment, adhering to the guidelines • install 176 FSTPs for faecal sludge treatment • Efficient deployment of desludging vehicles to transport the sludge from household septic tanks to the FSTP
Approach 4	Strengthen existing STP infrastructure by increasing the usage and fast tracking the development of sewer network and STPs in areas already proposed by the Government of Kerala	44.4%		• -100% utilization of the existing STPs, completion of the under construction and proposed STPs, totally accounting for 387 MLD. For the rest: • - Promote septic tank-based treatment.
Approach 5	Setting up of a sewer network and STP for all areas of Kerala with a population density of above 3000 people per sq. km and septic tank for the other areas without FSTP	46.8%	298 MLD centralized treatment + 3826 MLD onsite (septic tank	For the 25 high population city/towns: • Ensure 100% UGD connection • Establish STP of 298 MLD For other regions: • Promote septic tank-based treatment, adhering to the guidelines

30 In addition to efficient operation of 387 MLD of installed, under construction and proposed STPs as on January 2025 (Government of India (B), May 2022)

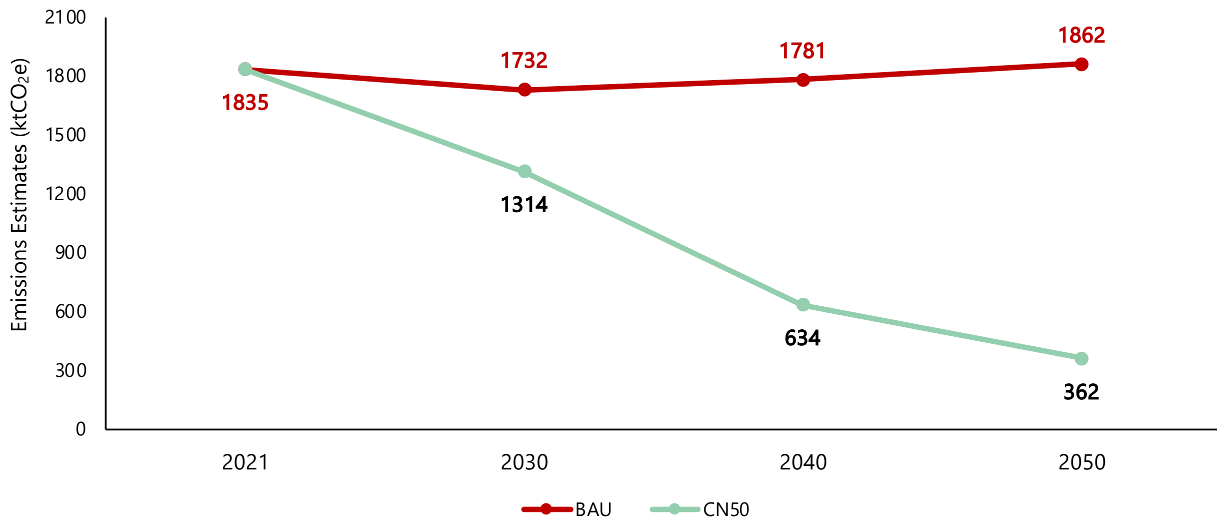


Figure 43: *Projected Emissions ($ktCO_2e$) of Domestic wastewater, in BAU and CN50 scenario, Kerala*

Interventions for Domestic Wastewater Management

- Set up adequate septic tanks at household level along with Faecal Sludge Treatment Plant (FSTP) systems at Grama Panchayat cluster level or Decentralised Wastewater Treatment Systems (DEWATS) for clustered settlements and remote housing entities (resorts/camping grounds/homestays).
- Ensure Underground Drainage (UGD) connection within the township to the respective STPs to maximise STP capacity utilisation.
- Promote the non-potable usage of treated wastewater for construction, landscaping and gardening of public spaces.
- Regulations for the use of treated water discharged from the STPs.
- Zero discharge policy for >2500 sqm buildings (for housing societies/ gated communities, education centres, office, companies).
- Regulate and ensure adherence to the septic tank construction guidelines
- Upgradation of soak pit and pit latrines to septic tanks
- Ensure formal system for sludge collection from septic tanks and its treatment at FSTPs.

3.2 Industrial Wastewater

In 2021, Industrial Wastewater emitted 40.03 $ktCO_2e$ representing 2.08% of the waste sector's total emissions. The Pulp and Paper Industry and Petroleum Industry were the major contributors in the industrial wastewater accounting for 49.43% and 41.63%, respectively.

Methodology

Emissions from industrial wastewater were projected using a compound annual growth rate (CAGR) approach, based on historical trends in industrial output and wastewater generation Under the CN50 scenario, progressive policy targets were incorporated to enhance wastewater treatment infrastructure. The State aims for 100% treatment coverage by 2050, with progressive interim targets of 30% by 2030 and 80% by 2040.

Scenario Based Projections[31]

Under the BAU scenario, emissions from industrial wastewater are projected to reach 40.41 ktCO_2e by 2050. In contrast, under the CN50 scenario, emissions are expected to decline due to improved treatment practices and compliance with stricter environmental norms. The year-on-year emissions projections under both BAU and CN50 scenarios are presented in Table 23.

Table 23: Scenario-based Projections of Industrial Wastewater Emissions (2021–2050)

Year	BAU GHG Emissions (ktCO_2e)	CN50 GHG Emissions (ktCO_2e)
2021	40.03	
2030	41.28	30.49
2040	40.85	12.38
2050	40.41	5.21

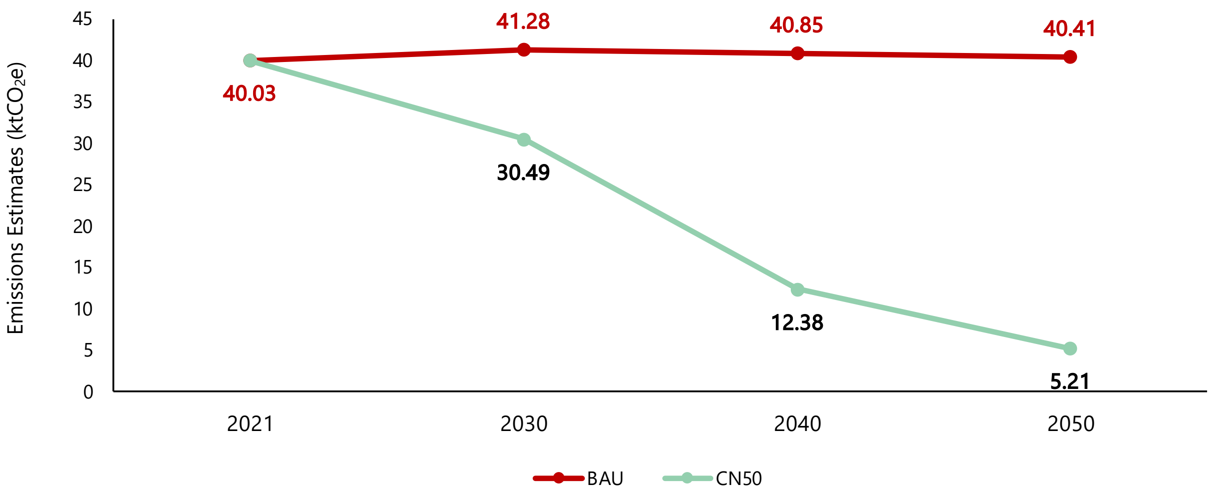


Figure 44: *Projected Emissions (ktCO_2e) of Industrial wastewater, in BAU and CN50 scenario, Kerala*

Interventions

1. **Strengthening Regulatory Oversight**

- Enforcement by Kerala State Pollution Control Board (KSPCB): KSPCB will regularly monitor effluent discharge standards, ensuring strict compliance with Consent to Operate (CTO) conditions.
- Online Monitoring Systems: Installation of Continuous Effluent Quality Monitoring Systems (CEQMS) in major industries to ensure real-time tracking of discharge parameters.

2. **Promotion of Common Effluent Treatment Plants (CETPs)**

- Cluster-based CETPs**:** For small and medium-scale industries, CETPs will be promoted to ensure cost-effective and compliant wastewater treatment.

3. **Adoption of Cleaner Production Technologies**

- Zero Liquid Discharge (ZLD): Promote industries to implement ZLD systems.

31 BAU industrial wastewater emissions were projected using a CAGR approach based on 2019–2023 wastewater generation trends from the Kerala GHG Inventory (Version 2). Despite emissions increasing between 2021-23, the overall period reflects a slight decline from 2019 levels. Therefore, there is a marginally negative CAGR and lower BAU projections.

- Reuse and Recycling**:** Mandate or incentivize industries to reuse treated effluent within plant operations to reduce freshwater demand and minimize external discharge.

4. Capacity Building and Awareness

- Training Programs**:** Conduct technical workshops for industry operators and technicians on advanced effluent treatment processes and environmental compliance standards.

3.3 Solid Waste Disposal

Emissions from Solid Waste Disposal decreased significantly by 59% from 113 ktCO_2e in 2005 to 46 ktCO_2e in 2021. Kerala has made remarkable strides in the field of solid waste management over the past few years, emerging as a model for decentralised, community-led practices. Through sustained efforts by local governments, active citizen participation, and the support of initiatives like the Suchitwa Mission, the State has made notable progress in reducing waste generation, promoting source-level segregation, and enhancing local-level treatment of both biodegradable and non-biodegradable waste. Notably, Municipal Solid Waste treatment increased from 52% in 2019–20 to 93% in 2022–23 (Government of Kerala (B), 2024), reflecting the impact of sustained policy focus and grassroots-level implementation.

A primary driver of this transition is the Haritha Karma Sena, a network of Self-Help Groups (SHGs) that play a pivotal role in the collection, segregation, and management of waste in both rural and urban areas. Their contribution has strengthened the decentralised model and enhanced community participation across the State. The adoption of decentralised models, widespread implementation of home composting, and the establishment of material recovery and resource recovery facilities have significantly reduced the burden on landfills and improved environmental outcomes. However, with growing urbanisation, changing consumption patterns, and increasing waste volumes, there is a need to strengthen and scale up the existing systems.

Building on this strong foundation, the proposed interventions are designed as a continuation and scaling-up of the already established systems. They aim to bridge existing gaps, improve coverage and efficiency, and ensure long-term environmental sustainability. Rather than reinventing the wheel, these efforts focus on expanding successful models, integrating new technologies, and reinforcing institutional capacities for a cleaner and greener Kerala.

Interventions for improved solid waste management:

- Adequate placement and management of waste collection bins, segregation centres.
- Sign boards and other monitoring at tourist hotspots to ensure proper waste management.
- Promotion of entrepreneurship in various aspects of waste management
- Facilitate infrastructure creation for waste to energy plants.
- Encourage 100% segregation and collection of waste at source. Set up and incentivise dry waste collecting centres at village/panchayat level.
- Facilitate dry and wet waste bin placement, collection, and management of waste in strategic tourist locations.
- Incentivise the informal sector and build public-private partnerships for segregation, collection, and disposal of waste.

4. Enhancing Carbon Sequestration Potential

In 2021, Kerala's gross greenhouse gas (GHG) emissions were 22165 ktCO_2e. The 'Land Use, Land Use Change, and Forestry' (LULUCF) sector offset approximately 66% of these emissions by removing 14,612 ktCO_2e, resulting in net emissions of 7553 ktCO_2e (Government of Kerala (C), 2026). Notably, forests accounted for 98% of total removals within the LULUCF sector.

Land use carbon sequestration:

Kerala boasts a forest cover of 56.76%, significantly higher than the national average of 25.17%. The forested area in the State has increased steadily from 17,324 sq. km in 2006 to 22,059.36 sq. km in 2021 (Forest Survey of India, 2023). Despite this positive trend in forest area, the carbon stock density of Kerala's forests declined from 127.95 tonnes per hectare in 2008 (Forest Survey of India, 2009) to 97.05 tonnes per hectare in 2021 (Forest Survey of India, 2023), indicating a reduction in forest carbon sequestration efficiency over time. State's mitigation potential lies in enhancing carbon sequestration through improvements in forest density, structure, and ecological quality. Strengthening forest carbon stocks through restoration, enrichment, and improved management of existing forests can enhance carbon removal while delivering co-benefits such as improved soil health, biodiversity conservation, and sustainable livelihoods for local communities.

Blue carbon capture:

Kerala's 590 km-long coastline offers significant potential for blue carbon capture. Blue carbon refers to the carbon sequestered and stored in coastal and marine ecosystems such as mangroves, seagrasses, and salt marshes. These ecosystems are highly efficient in absorbing atmospheric carbon dioxide and storing it in both plant biomass and sediments. Recent field-based studies indicate that Kerala mangrove ecosystems store approximately 139.8 tC ha^{-1} as total ecosystem carbon, with soil carbon contributing around 58% of the total stock within the upper soil layers, thereby underscoring the dominant role of sediment carbon storage in coastal wetland systems (Harishma, Sandeep, & Sreekumar, 2020).

Kerala's mangrove cover has declined, and is currently estimated to be around 21.15 sq. km (Government of Kerala (A), 2019). The State is also rich in wetland ecosystems, with 169 natural coastal wetlands—including lagoons, creeks, and beach areas—spanning a total of 409 sq. km (Government of Kerala (D), 2022). The State's extensive backwaters host three Ramsar sites of international ecological importance: Ashtamudi Lake, Sasthamkotta Lake, and the Vembanad-Kol wetlands.

The current status of mangroves and coastal wetlands in Kerala underscores both a challenge and a vital opportunity. Restoration and conservation of these ecosystems can unlock substantial blue carbon sequestration potential, contributing meaningfully to climate mitigation efforts while also supporting biodiversity, enhancing coastal resilience, and sustaining livelihoods.

Methodology

The CO_2 removal estimated at a 2021 baseline of 14,626 ktCO_2e under the BAU scenario can be significantly enhanced through a strategic, multi-pronged approach to land and coastal ecosystem management. This approach includes identifying opportunities for large-scale afforestation and reforestation, with a focus on native and fast-growing species to optimize carbon uptake. Agroforestry practices were also evaluated for their dual benefits in supporting carbon sequestration and rural livelihoods. Simultaneously, scenarios were developed to improve carbon stock density within existing forests through sustainable management and enrichment planting. In addition, the restoration potential of degraded coastal ecosystems—including mangroves, seagrasses, and other wetlands—was assessed to boost blue carbon sequestration along the coastline, contributing to both climate mitigation and coastal resilience.

Scenario based projections

Under the BAU scenario, maintaining the current rate of carbon stock increase, either through continued forest cover expansion and/or enhancement of carbon stock density, is projected to sustain the current annual CO_2 removals of 14,626 ktCO_2e by 2050. However, CO_2 sequestration can be further enhanced through a combination of approaches, including increasing tree cover through agroforestry and social forestry, improving the carbon stock density of existing forests, and restoring degraded mangrove patches. Under the more ambitious CN50 scenario, this annual carbon sequestration potential could rise significantly to 23912 ktCO_2e/year. The scenario-based projections are detailed In the Table 24

Table 24: Scenario-based projections

Year	BAU (ktCO_2e)	CN50 - Additional Carbon Sequestration (ktCO_2e)/year			Total (ktCO_2e)/ year
		Restoration of Mangroves	Agro/Social forestry	Enhancement of forest carbon stock density	
2021	-14626				-14626
2030	-14626	-309	-139	-4610	-19684
2040	-14626	-928	-416	-7354	-23325
2050	-14626	-1237	-694	-7354	-23912

Interventions for enhancing sequestration potential of land and blue carbon

The projected carbon sequestration of 14626 ktCO_2e/year under BAU can be enhanced to a total of 23912 ktCO_2e/year under the CN50 scenario through a combination of targeted land- and blue-carbon interventions. The key measures include:

a. **Expansion of Social and Agroforestry:** Promote agroforestry practices on 75% of the 841.16 sq. km of land (National Remote Sensing Centre, 2024) classified as barren/wasteland and fallow land. This translates to approximately 630.87 sq. km of land being brought under productive green cover, with a projected carbon sequestration potential of 694 ktCO_2e/year

b. **Restoration of Mangrove Forests:** Restore the mangrove cover from current extent of 21.15 sq. km (Government of Kerala (A), 2019) to 100.60 sq. km by 2050, with a strong emphasis on sustained protection and management. The carbon sequestration potential from this mangrove restoration is projected to be at 1237 ktCO_2/year.

c. **Enhancement of Forest Carbon Stock Density:** The pathway assumes a substantial increase in canopy density and carbon stock through a combination of afforestation, assisted natural regeneration (ANR), and improved forest management practices. This transition is expected to result in an overall ~40% increase in forest carbon stock, with an estimated sequestration potential of ~7,354 ktCO_2e per year. Strengthening forest structure and biomass through these measures will not only enhance long-term carbon sequestration but also improve ecosystem resilience, biodiversity, and watershed functions.

These integrated strategies represent a transformative opportunity to scale up carbon sequestration across terrestrial and coastal ecosystems, contributing significantly to Kerala's carbon neutrality goals.

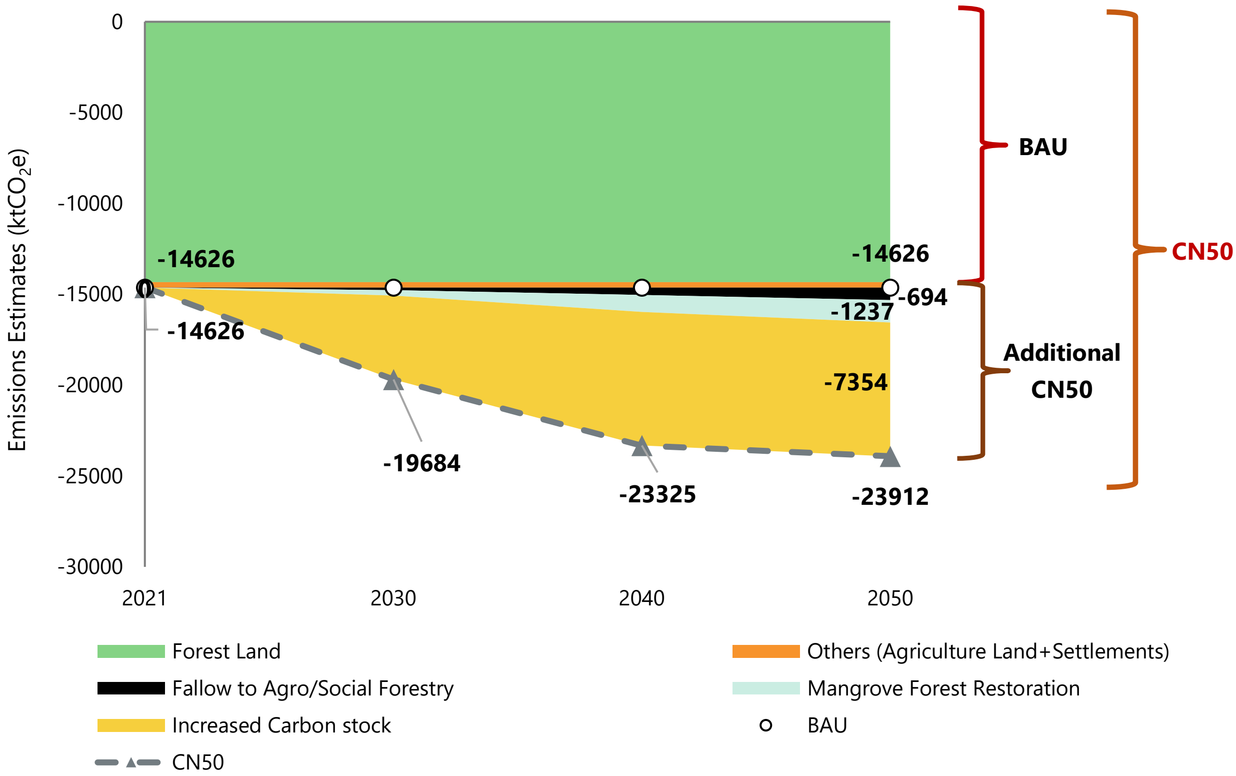


Figure 45: *Projected Total CO_2 Sequestration Potential under BAU and CN50 scenarios*

Chapter 5

Aggregate Results & Key Insights

This chapter presents the integrated results of the sectoral analyses, bringing together projections from both energy and non-energy sectors to outline Kerala's pathway towards carbon neutrality. By aggregating emissions, mitigation potentials, and transition trajectories across sectors, the analysis provides a comprehensive view of the State's overall decarbonisation outlook. It highlights the interplay between sectors, identifies key drivers of emissions reduction, and assesses the cumulative impact of proposed interventions.

Kerala's gross GHG emissions[32] stood at 22.18 $MtCO_2e$ in 2021 and under the BAU scenario, are projected to reach 25.90 $MtCO_2e$ by 2050, reflecting a 16.77% increase under current trends in energy use, waste management, and other sectors. Further, emissions are expected to peak around the year 2030 at 26.70 $MtCO_2e$ before gradually declining towards 2050 within the BAU trajectory. The energy sector is projected to drive the majority of this increase between 2021 and 2050 (3.18 $MtCO_2e$ or 85.37% of the total rise of 3.72 $MtCO_2e$). This growth is expected to be led primarily by the transport and industrial sectors.

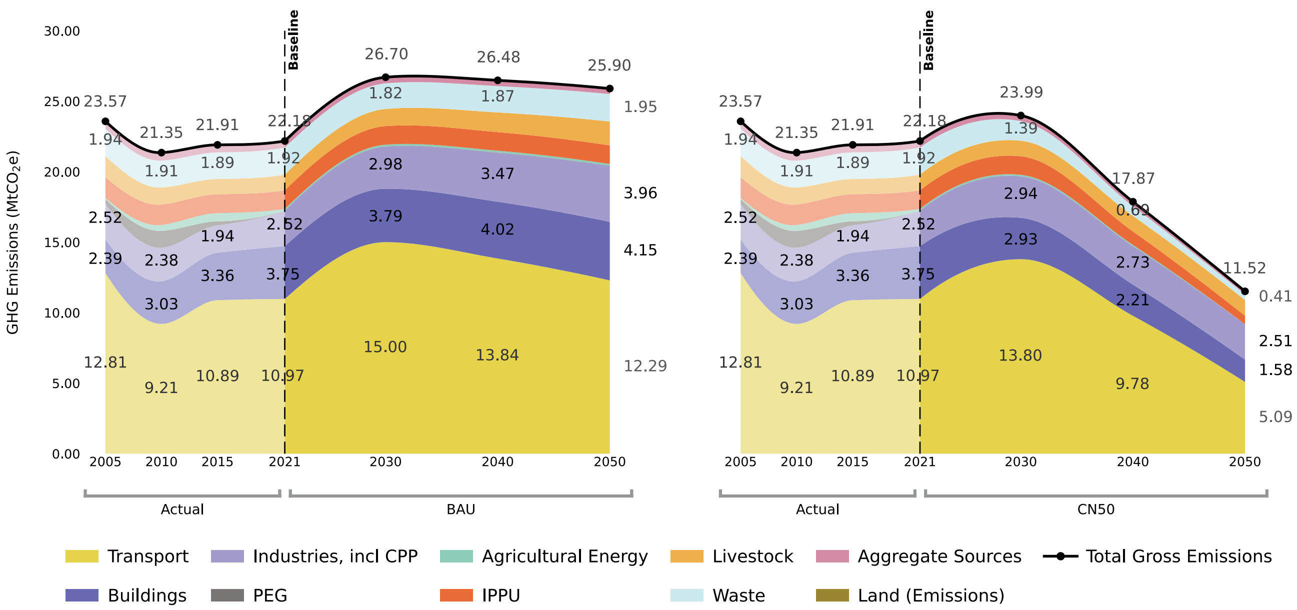


Figure 46: *Gross GHG Emissions in Kerala, across BAU and CN50 Scenarios*

32 In the GHG estimates, net emissions include the LULUCF category, while it is excluded from gross emissions, resulting in gross emissions of 22.16 $MtCO_2e$. However, in the BAU and CN50 scenarios, emissions from the LULUCF category have been included in the gross emissions estimates to ensure the estimates remain comprehensive, increasing gross emissions to 22.18 $MtCO_2e$.

Through dedicated interventions aimed at electrification, fuel switching and energy efficiency across energy sectors, and improved waste management practices, as much as **55.54**% of the projected gross emissions in BAU could be abated *(Figure 46)*. Further, enhancing carbon sinks through mangrove restoration, improving the carbon stock density of existing forests, and undertaking additional interventions to increase sequestration could enable Kerala to achieve net removal of negative GHG emissions of **12.40** $MtCO_2e$ by 2050 *(Table 25)*.

Table 25: Summary of sector wise emissions ($MtCO_2e$) in Kerala under BAU and CN50 scenarios

S.No	Sectors	Actual 2021	BAU			CN50		
			2030	2040	2050	2030	2040	2050
A.	Energy	17.36	21.92	21.49	20.55	19.78	14.80	9.18
A.1	Agriculture Energy	0.12	0.13	0.13	0.14	0.11	0.08	0.00
A.2	Industry, incl. Captive	2.52	2.98	3.47	3.96	2.94	2.73	2.51
A.3	Buildings	3.75	3.79	4.02	4.15	2.93	2.21	1.58
A.4	PEG	0.01	0.01	0.01	0.01	0.00	0.00	0.00
A.5	Transport	10.97	15.00	13.84	12.29	13.80	9.78	5.09
B.	Non-Energy	-9.81	-9.84	-9.64	-9.28	-15.48	-20.26	-21.58
B.1	IPPU	1.32	1.32	1.32	1.32	1.32	0.96	0.60
B.2	Waste	1.92	1.82	1.87	1.95	1.39	0.69	0.41
B.3	Livestock	1.11	1.21	1.40	1.69	1.10	1.10	1.11
B.4	Aggregate Sources	0.45	0.42	0.40	0.38	0.38	0.30	0.20
B.5	Land (Emissions)[33]	0.014	0.014	0.014	0.014	0.014	0.014	0.014
B.6	Sequestration[34]	-14.63	-14.63	-14.63	-14.63	-19.68	-23.32	-23.91
C.	Total Gross (A+B-B.6)	22.18	26.70	26.48	25.90	23.99	17.87	11.52
D.	Net Emissions (C+B.6)	7.55	12.08	11.86	11.27	4.30	-5.45	-12.40

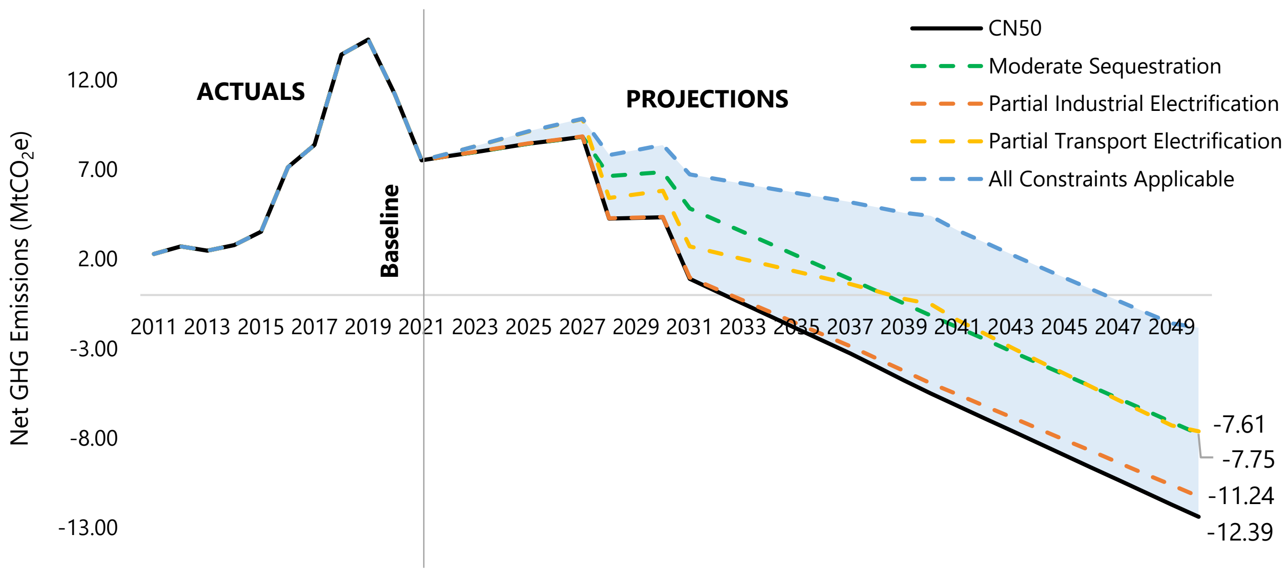
33 Land (Emissions) includes emissions from Grassland, Other Land (Barren Land/ Unculturable/wastelands) and Biomass burning in Forestland categories.

34 Sequestration includes removals from Land, Agriculture Land and Settlements categories

While the evolving economic and technical landscape may impact the pace of action vis-a-vis interventions proposed under the CN50 scenario, carbon neutrality would still remain achievable.

The CN50 scenario proposes a decarbonisation trajectory based on a robust set of interventions across energy and non-energy sectors. Harnessing the current policy and regulatory momentum – these interventions include 100% EVs in new sales of 2Ws and 3Ws by 2040, and 4Ws by 2050, 50% share of households using electric cookstoves, 50% fallow land conversion etc. As Kerala's economy grows and its technical landscape evolves over the next two decades, inherent variables may impact the pace of implementation. Despite it, carbon neutrality could still be reached well before the target year of 2050 by 2045.

These sensitivities could be in the form of lesser than proposed electrification among transport and industrial sectors, or lower rate of sequestration. In transport, for instance, both BAU and CN50 assume a certain level of electrification – driven by the Draft State EV Policy 2025. If only 50% of this electrification takes place, attainment of net negative would deviate from 2032, but could still be reached by 2040.



Scenarios	Description	Carbon Neutral Year
Partial Industrial Electrification	50% less electrification of heating process, against CN50 target	2033
Moderate Sequestration	50% lesser area restored, against CN50 target	2039
Partial Transport Electrification	50% lesser electrification of transport fleet, against CN50 target	2039
All Constraints Applicable		2047

Figure 47: *Net GHG Emissions in $MtCO_2e$, across scenarios*

Deep electrification across energy sectors will act as a strategic enabler for economy wide decarbonisation.

Perhaps the most significant systemic inference from the CN50 scenario is about the economy-wide transformation of energy security. In the current fossil-fuel-dependent system, energy security is fundamentally a question of access to global commodity markets - oil and gas in particular, whose prices are set by geopolitical dynamics far beyond any single country's control. Price spikes, supply disruptions, and producer-country policy decisions all transmit directly into domestic energy costs and inflation. Deep electrification dissolves this dependence at the root. When the energy system is built around clean electricity, generated domestically from renewable resources, the primary energy input becomes largely immune to international commodity price volatility.

In the road transport sector, the decarbonisation plan envisions a rapid transition to 100% electrification of new sales for two and three wheelers in the near term, by 2040, followed by an almost complete electrification of four-wheelers, passenger vehicles and light goods vehicles in the longer term, between 2045 and 2050. However, a residual share of diesel consumption is expected to persist, particularly in heavy goods vehicles such as trucks, where electrification remains more challenging.

Similarly, scaling up the adoption of electric cookstoves across residential (around 55 lakh households) and commercial segments can significantly reduce dependence on conventional LPG by shifting end-use energy demand to clean electricity. In the industrial sector, deep electrification involves substituting fossil fuel-based heating processes with electricity across low, medium, and high-temperature applications, wherever technically feasible. Taken together, electrification across these key sectors (excluding public electricity generation) has the potential to deliver substantial emissions reductions, cumulatively abating 11.35 $MtCO_2e$ annually by 2050.

Multi-fold increase in the electricity demand by 2050; therefore, higher integration of renewable sources would be required to meet this demand.

Such a shift from fossil fuel based to electricity-based economy is projected to increase State's annual electricity demand multifold by 2050. The state electricity demand would increase to **123.70** TWh in 2050, a nearly five-fold increase from 2021. This increase would primarily be contributed by industries (17.31 TWh) and transport (14.56 TWh). In buildings, electricity demand would increase due to higher heat days and an increased use of cooling solutions, but would subsequently get adjusted as electricity savings rise on account of adoption of energy efficient ACs and BLDC fans.

To meet this demand and attain the 100% RE supply stature for the state, as much as **65.06** GW of RE based installed capacity would be required by 2050. In terms of solar rooftop addition, Kerala already ranks very high among other states in India. Similar efforts are required to enhance the utility scale solar capacity addition to take the existing capacity to 50.52 GW (76.42% of total RE) by 2050. Further, dedicated efforts would also be required to reach 11.28 GW wind capacity by 2050 (17.02%). *These estimations with additional details are provided in Part III of this report.*

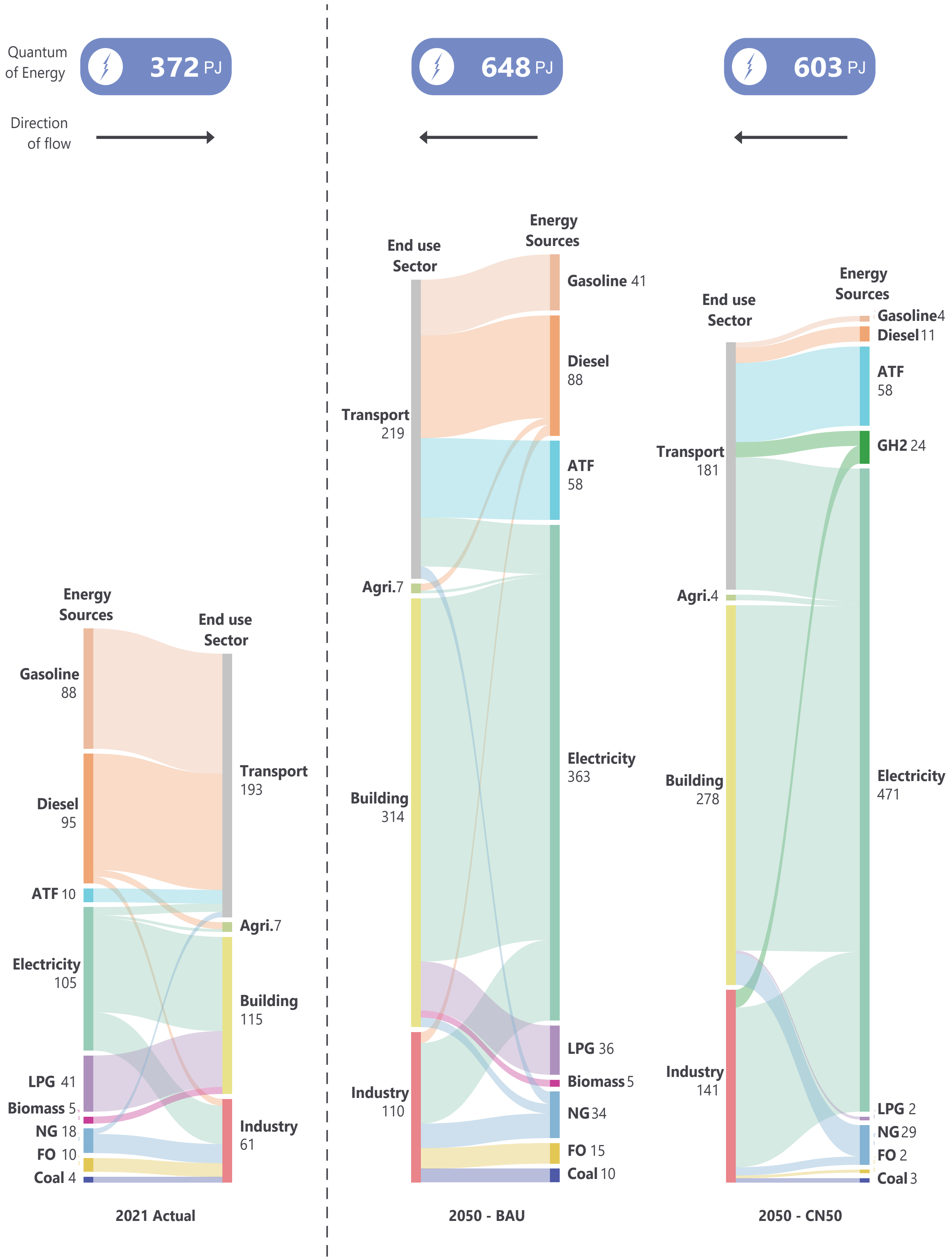


Figure 48: *Energy sources and respective end-use sectors flow diagram in Kerala across 2021 actual and 2050- BAU and CN50 scenario*

(**Note:** FO = Fuel oil, NG= Natural Gas, ATF=Aviation Turbine fuel, and H2= Green Hydrogen)

Beyond the energy transition, Kerala's pathway to carbon neutrality requires a balanced approach that combines substantial reductions in non-energy sector emissions through decarbonisation of IPPU, agriculture, and waste sectors, with significant enhancement of carbon sequestration through forests, agroforestry, coastal ecosystems, and other natural carbon sinks.

Curtailment of IPPU emissions would be possible in future with technological advancement, and market development.

IPPU emissions account for 5.94% (1.32 $MtCO_2e$) of total gross emissions in Kerala, with ammonia production contributing almost 54.96% of it. Given Kerala's strong policy mandates and push for green hydrogen, these ammonia-led IPPU emissions could be fully abated through a 100% replacement of natural gas with green hydrogen by 2050. The residual emissions of 0.6 $MtCO_2e$ from metal and mineral industries could be subsequently captured as the technology for CCUS advances and the market develops.

Sustainable agriculture and advanced waste management can reduce non-CO_2 emissions, particularly methane and nitrous oxide emissions, by more than 50% by 2050.

The shift to sustainable agriculture practices and livestock management practices can reduce projected agriculture sector emissions by 36.72% by 2050. Further, comprehensive domestic wastewater management (through adding additional 194 MLD of centralised aerobic treatment over and above the existing capacity and adding new 176 faecal sludge treatment plants with septic tanks), effluent treatment plants with continuous monitoring systems and zero liquid discharge for industrial wastewater, and continued municipal solid waste management through zero landfill can reduce projected waste sector emissions by approximately 78.81% by 2050. These interventions together will reduce the projected non-energy, in other words, the non-CO_2 emissions from 4.02 $MtCO_2e$ under the BAU scenario to 1.72 $MtCO_2e$ under the CN50 scenario.

Enhancement of sequestration by harnessing the potential of land use and blue carbon capture would be equally paramount – leading to net negative emissions by 2050.

Carbon neutrality for the State significantly depends on increasing CO_2 removal through land use, agroforestry and social forestry, as well as enhancing the carbon stock densities of the existing forests, and restoring mangrove patches. Carbon sequestration can be enhanced by improving forest density, structure, and ecological quality. Strengthening forest carbon stocks of the existing forests will not only enhance carbon removal but will also deliver co-benefits such as improved soil health, biodiversity conservation, and sustainable livelihoods for local communities.

The carbon sequestration potential can be enhanced through repurposing 75% of 841.16 sq. km of barren and fallow land for agroforestry and social forestry, along with increasing carbon stock densities in existing forests. The State's coastline also offers significant blue carbon potential through restoration of mangroves, seagrasses, salt marshes, and other wetlands, with mangrove cover projected to increase from 21.15 sq. km to 100.60 sq. km under effective ecosystem management. These interventions together are estimated to enhance total carbon sequestration to approximately 23.91 $MtCO_2e$.

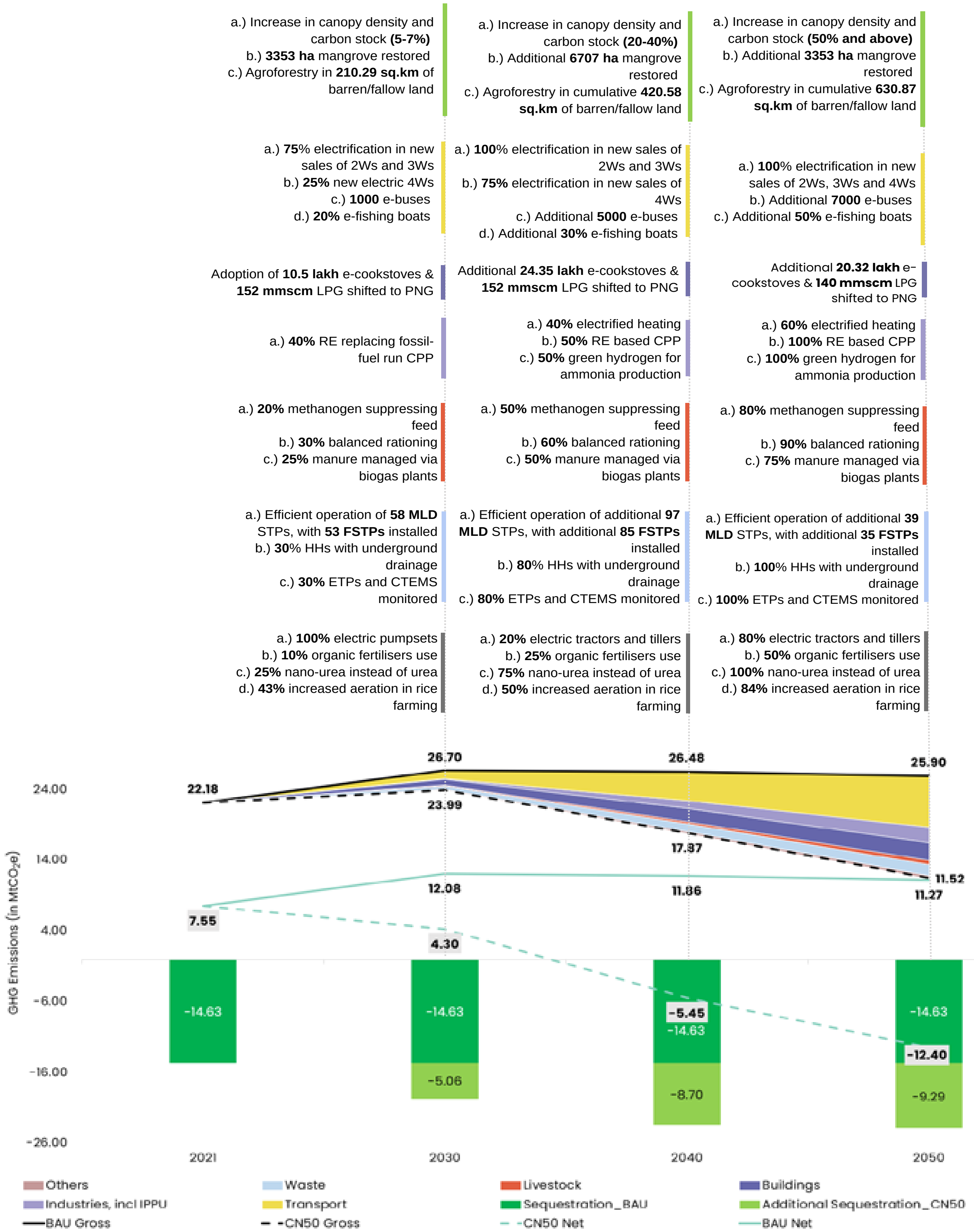


Figure 49: *Timeline wise sectoral interventions*

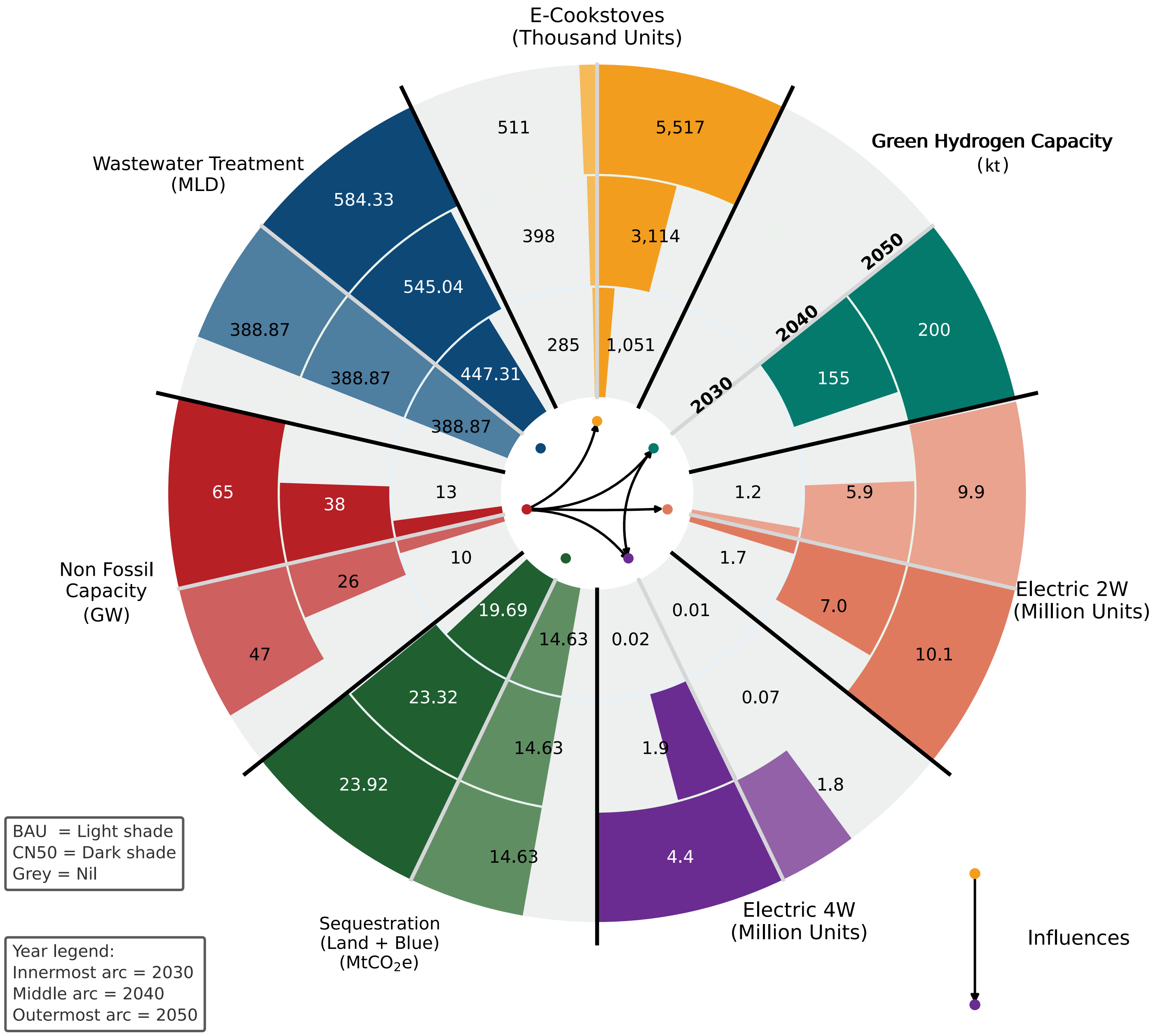
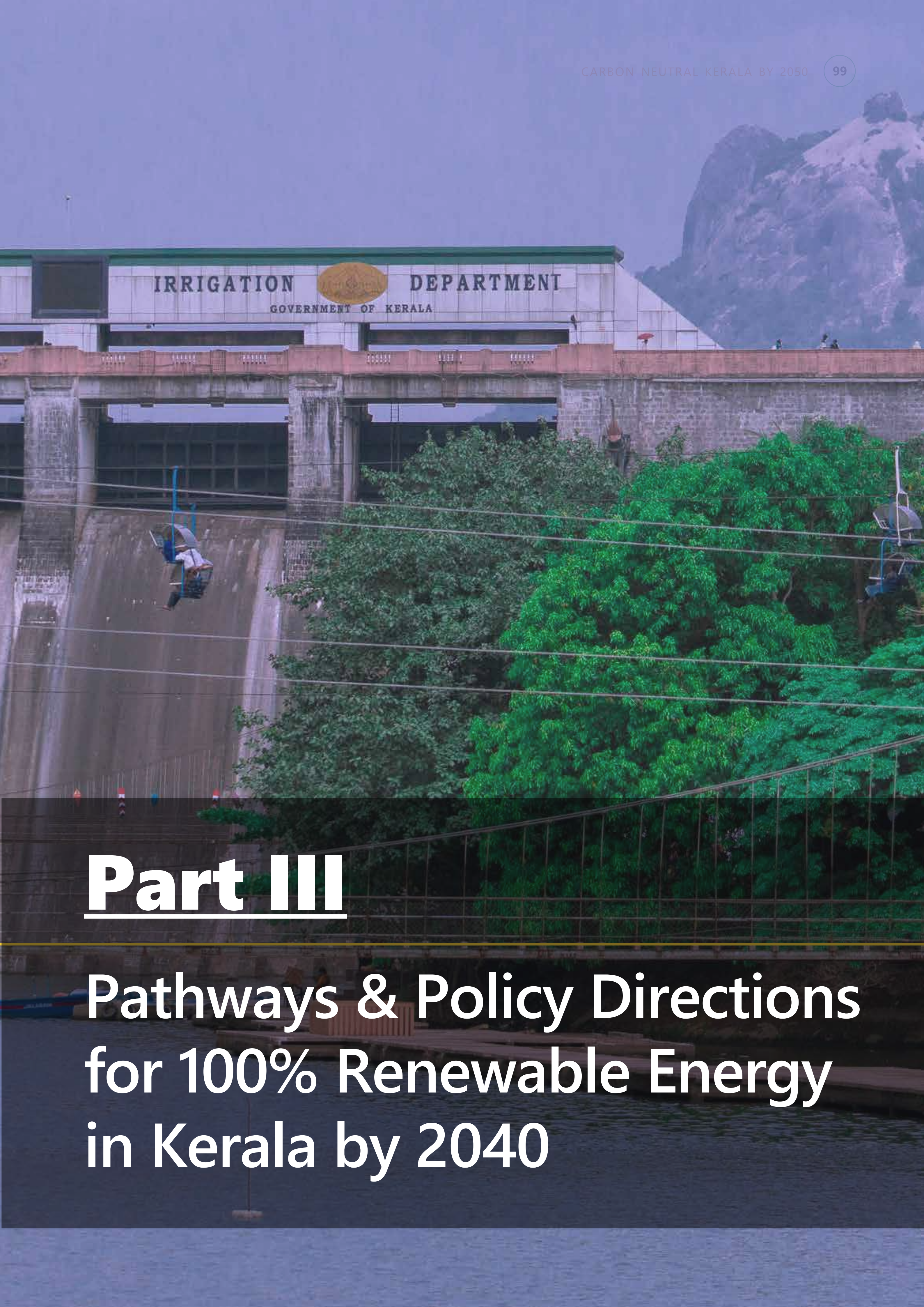


Figure 50: *Major components of the decarbonisation plan, with comparison between BAU and CN50*

Idukki, Kerala

Malampuzha Dam, Kerala



Part III

Pathways & Policy Directions for 100% Renewable Energy in Kerala by 2040

Chapter 6

Transitioning Kerala's Electricity: Towards 100% RE by 2040

As of March 2025, Kerala's total installed power capacity (based on geographical location) was 4412.15 MW[35], with an 87.84% share of RE (Kerala State Electricity Board Limited (A), 2025). Despite the absence of coal-based generating sources within its geographical boundaries, Kerala heavily relies on thermal power-based electricity at 49.65% (Government of India (C), n.d.) (Table 26) sourced from coal power plants elsewhere in India. In light of this, the State has already set ambitious targets to reduce this reliance, aiming to meet 100% of its energy needs through renewable sources by 2040 (Government of Kerala (B), 2026).

Achieving this goal requires overcoming a significant resource gap: Kerala's internal renewable potential is estimated at 18.92 GW (Government of India (A), 2025), while the capacity required to satisfy the projected 123.49 TWh ex bus demand[36] by 2050 is between 47.39 GW and 66.11 GW. Consequently, the State's roadmap emphasizes not only the expansion of local solar and wind infrastructure but also the necessity of embracing inter-state renewable energy trade and installing 15.00–21.00 GW of energy storage to ensure grid reliability.

Table 26: Source wise power procurement in Kerala, for last decade

Row Labels	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	2022-23	2023-24
Coal	58.90%	68.26%	63.33%	61.56%	62.90%	60.78%	56.53%	57.70%	49.65%
Hydro	27.43%	17.24%	21.85%	28.09%	20.67%	25.98%	34.58%	29.88%	16.97%
Nuclear	4.24%	7.21%	7.09%	5.17%	7.53%	8.10%	8.99%	8.51%	7.31%
Oil & Gas	1.22%	0.21%	0.27%	0%	0%	0.36%	0%	0%	0%
Small Hydro	1.48%	0.97%	1.23%	1.03%	1.00%	1.62%	2.18%	2.04%	1.42%
Solar	0%	0.06%	0.23%	0.37%	0.40%	0.66%	1.93%	1.56%	2.30%
Trading & Others	6.47%	5.66%	5.55%	3.37%	7.06%	2.06%	-5.37%	-0.99%	21.31%
Wind	0.25%	0.39%	0.44%	0.41%	0.44%	0.45%	1.15%	1.3%	1.04%

Source: India Climate & Energy Dashboard, State Reports

35 Including IPPs and captive renewable plant

36 This is the net grid demand, calculated as a sum of total electricity demand and T&D Losses, with subtraction of RTS generation and captive power generation. (Chapter 3)

To navigate this transition towards renewable energy and ensure a reliable power supply in the State, this assessment proposes an optimal supply capacity mix by using a capacity expansion model. This model aims to achieve resource adequacy while aligning with the ambitious 100% renewable energy target by 2040. This approach promotes energy security and grid resilience by transitioning away from imported thermal power.

This chapter details the future supply and generation mix, role of energy storage, and the pathway to reach the 2040 RE goal under BAU and CN50 scenarios. It also examines variations in the supply mix, considering sensitivities related to the cost of energy storage systems, the addition of nuclear and hydro power capacities, and shifting night peak demand to daytime.

For the purpose of electricity system planning and assessment of the 100% renewable electricity target by 2040, this chapter expresses electricity demand as ex-bus demand, derived by adding transmission and distribution losses to the gross electricity requirement from the CN50 pathway. The gross electricity requirement corresponds to the consumer-side electricity demand reported in preceding chapters. Throughout this chapter, electricity demand refers to ex-bus demand, except where explicitly noted. This accounting approach is adopted to align the analysis with power system planning conventions for renewable capacity, storage, and system adequacy assessment.

Methodology and Assumptions

To generate the optimal capacity mix for the region, the TIMES model was utilised to estimate the demand for electricity in conjunction with Python for Power System Analysis (PyPSA), an open-source integrated power system modelling tool. These models simulate and optimise investment decisions within electrical power systems across multiple investment years to fulfil required power demand. The model optimises capacity additions based on investment costs over each technology's lifespan, resulting in an optimal power capacity mix tailored to meet demand within the state.

Kerala is treated as a single load (demand) centre and the model evaluates the required power capacity to satisfy demand in each five-year interval up to 2050. Transmission network capacity constraints within the state are not explicitly modelled; the framework operates under a copper-plate assumption for electricity supply. The model is run with grid-level unit commitment constraints to analyse operational aspects, the role of energy storage, curtailment, and other pertinent factors.

Modelling Assumption

- Aligned with the policy directive of achieving 100% renewable energy by 2040, the model assumes no addition of new coal capacity beyond already committed or contracted projects. However, certain existing thermal plants have contractual obligations extending until 2042–2043, which delays their absolute retirement. Accordingly, a 700 MW coal capacity currently under contract has been retained in the portfolio through 2050 across all scenarios, although its generation share falls below 1% by 2045 in every case.
- Kerala has an estimated hydroelectric potential of 3.12 GW, of which approximately 2.15 GW has already been developed as of March 2024. The model includes existing hydro assets – comprising run-of-river (480.00 MW) and pumped storage (1,668.00 MW) capacity – alongside phased additions of new conventional hydro capacity

consistent with ongoing planned projects, reaching up to 1,112.00 MW by 2040 under CN50. A five-year average plant load factor of 47.00% has been considered for hydro with storage. The unusually high Plant Load Factor (PLF) of 57% recorded in 2021–22, driven by exceptional rainfall, is treated as an outlier and excluded from the baseline.

- The wind potential of Kerala and neighbouring states at 150 metre hub height is considered.
- Inter-state market procurement is modelled as a flexible import option, with capacity limits set to reflect the structural reality that Kerala's in-state renewable resource base is insufficient to meet projected future demand on its own.
- Capital and operational costs, operational parameters, and other technology-specific assumptions are detailed in Annexure 3.

Renewable Energy Resource Potential

In Kerala, the in-state renewable energy resource potential remains materially constrained relative to projected future electricity demand. Ground-mounted solar potential is estimated at 12.40 GW (Government of India (A), 2025), on-shore wind (at 150 m AGL) at 2.62 GW, conventional hydro at 2.47 GW, small hydro at 0.65 GW, and biomass at 0.78 GW – giving a combined in-state renewable potential of approximately 18.92 GW (Table 27). This potential falls well below the supply capacity requirements in either the BAU or CN50 scenario beyond 2030[37], making inter-state renewable energy trade a structural necessity.

There is a pressing need for a holistic and exhaustive assessment of the state's full renewable energy potential, including floating solar, agri-photovoltaic systems, rooftop potential, offshore wind, and other decentralised applications of renewable energy. Procuring renewable electricity from neighbouring states with surplus energy resources emerges as the most feasible approach to supplement the shortfall in resource potential within Kerala. Leveraging inter-state renewable energy trade strengthens energy security, accelerates the transition, and ensures a reliable and cost-effective power supply for the state.

Table 27: Resource potential renewable energy, (in GW), in Kerala

Solar	Wind (on-shore)	Hydro	Small hydro	Biomass	Total
12.40	2.62	2.47	0.65	0.78	18.92

Source: Renewable Energy Statistics 2024-25

Electricity demand by 2050

Kerala's electricity sector is poised to expand substantially over the next three decades, driven by economic growth, industrial expansion, the rising demand for cooling due to increasing heat stress, and the accelerated electrification of transport, industry, and cooking under the CN50 pathway. This trend was already evident in March 2024, when extreme heat conditions led to record-breaking power consumption in the State.

The state's electricity demand is projected to surge significantly. Under the BAU scenario, net grid demand rises from 41.59 TWh in 2030 to 65.98 TWh in 2040 and 90.16 TWh by 2050, with peak demand increasing from 7.16 GW in 2030 to 15.52 GW by 2050. Under the CN50 scenario, demand reaches 46.91 TWh in 2030, 88.56 TWh by 2040, and 123.49 TWh by 2050, with peak demand rising to 21.03 GW, a nearly four times increase compared to current consumption

37 This occurs only after 2030. In 2030, the potential still remains significantly higher than the required supply capacity.

levels. The carbon-neutral pathway creates a significantly larger electricity system than BAU, requiring commensurate investment in firming capacity, inter-state transmission, and storage to manage a more electricity-intensive economy. Enhancing the load factor is expected to be achievable through demand response measures, including load shifting to non-peak hours, behavioural changes, and decentralised generation. The sensitivity scenario that explicitly models this shift – CN50-DS – demonstrates the material system cost reductions possible when peak demand coincides more closely with solar generation.

Peak demand and load curve

In May 2024, Kerala experienced a historic peak peak power demand of 5.80 GW, marking a 19.62% increase over the demand recorded during the same month in the previous year. This surge in demand can be attributed to the rising summer temperatures. Typically, peak demand in Kerala occurs between March and May, followed by a decline with the onset of the monsoon in June. After the monsoon, demand gradually rises again and remains relatively stable throughout the year due to mild winters. Further, irrespective of the season, peak demand consistently occurs during the evening hours. This pattern is largely driven by the residential loads, which constitute a substantial share of the state's electricity consumption. By 2050, peak demand is projected to reach 15.52 GW and 21.03 GW under the BAU and CN50 scenarios respectively. The analysis also assumes that the 2050 electricity demand curve will follow a pattern similar to that of the FY 2025 demand pattern.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
2015-16	3512	3632	3448	3391	3411	3491	3469	3418	3466	3537	3666	3856
2016-17	3996	3932	3494	3369	3528	3505	3598	3595	3526	3594	3688	3798
2017-18	3862	3837	3597	3452	3490	3529	3535	3645	3553	3543	3706	3870
2018-19	3934	3997	3533	3489	3342	3638	3644	3678	3727	3699	3833	4228
2019-20	4300	4205	4071	3816	3591	3552	3576	3714	3705	3785	3954	4171
2020-21	3775	3701	3292	3192	3526	3354	3577	3660	3693	3731	3914	4269
2021-22	4235	3880	3593	3618	3591	3761	3742	3680	3825	3889	4038	4364
2022-23	4370	4168	3975	3646	3791	3851	4336	3919	3945	3980	4198	4504
2023-24	5010	4846	4600	3983	4356	4107	4143	4293	4260	4340	4827	5284
2024-25	5631	5797	4383	4167	4247	4336	4440	4489	4466	4506	5000	5334

Figure 51: *Monthly Peak demand (2016-2024)*

Source: Grid India (GRID India)

Note: green to red colour shows the increase in the intensity of the peak demand across the calendar year

Daily Load Profile

Examining daily load curves offers valuable insights into the shifting demand patterns and highlights how peak demand formation has evolved over time. Peak demand days are consistently observed between March to May. In recent years, the timing of the daily peak has stabilised around late evening 22:00 hours. *(Figure 52)*.

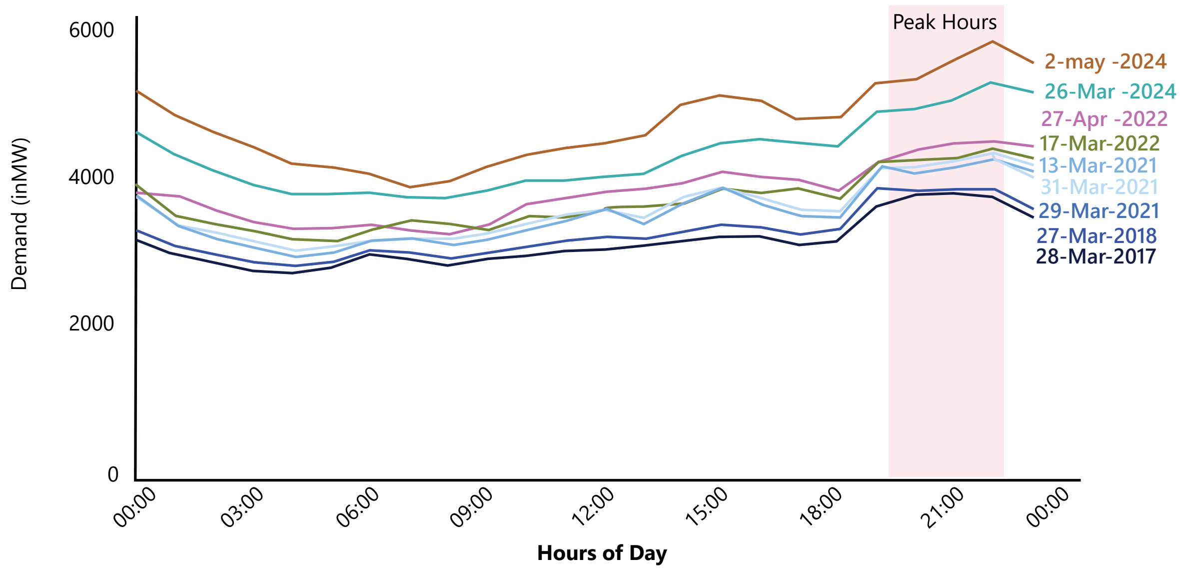


Figure 52: *Hourly demand curve of peak demand day from year 2017 till 2024*

Electricity System Results

Table 28: Demand and Supply projections, in the BAU and CN50 scenario

Scenarios	2021	BAU (Projections)			CN50 (Projections)		
		2030	2040	2050	2030	2040	2050
Electricity Demand (TWh)							
Agriculture	0.38	0.41	0.43	0.48	0.41	0.59	0.80
Industries (incl. CPP)	6.59	10.41	13.90	17.19	11.38	23.56	34.50
Residential	12.76	20.97	32.54	39.58	21.92	32.64	38.55
Services and others	5.27	9.55	16.95	26.03	9.55	16.95	26.03
Transport	0.84	1.86	4.62	9.25	4.48	15.82	23.82
Captive consumption (RTS)	0.16	5.18	8.23	9.28	5.18	8.23	9.28
T&D Losses	3.34	4.97	7.16	8.30	5.75	8.62	10.47
	12.92%	11.50%	10.46%	8.97%	12.04%	9.62%	8.46%
Total Ex-bus demand	**27.88**	**41.59**	**65.98**	**90.16**	**46.91**	**88.59**	**123.49**
Peak Demand (GW)							
Peak Demand	4.40	7.16	11.37	15.52	8.07	15.20	21.03
Supply capacity@ (GW)							
Coal	2.20	3.60	2.16	0.70*	3.60	2.16	0.70*
Gas	0.53	0.00	0.00	0.00	0.00	0.00	0.00
Hydro (incl. Small Hydro)	2.13	2.26	2.76	2.76	2.26	3.26	3.26

Scenarios	2021	BAU (Projections)			CN50 (Projections)		
		2030	2040	2050	2030	2040	2050
Nuclear	0.37	0.37	0.35	0.35	0.37	0.35	0.35
Solar	0.65	3.41	14.69	35.46	4.58	22.56	50.52
Wind	0.06	4.33	8.23	8.12	5.89	11.39	11.28
Total Capacity	**5.95**	**13.96**	**28.18**	**47.39**	**16.70**	**39.71**	**66.11**
Storage (GW/ GWh)	-	1.7/1.9	8/38	15/105	3.7/4.2	12/63	21/153
Grid Emission Factor (kg CO_2eq / kWh)							
Emission Factor	0.58	0.26	0.06	0.01	0.21	0.04	0.01

@Capacity for 2021 is the contractual capacity of Kerala i.e. it includes the joint and central share of utilities as well.

*700 MW of coal capacity remains in the portfolio through 2050 across all scenarios due to contractual obligations; its contribution to total generation falls below 1% by 2045 in every case

Supply Mix

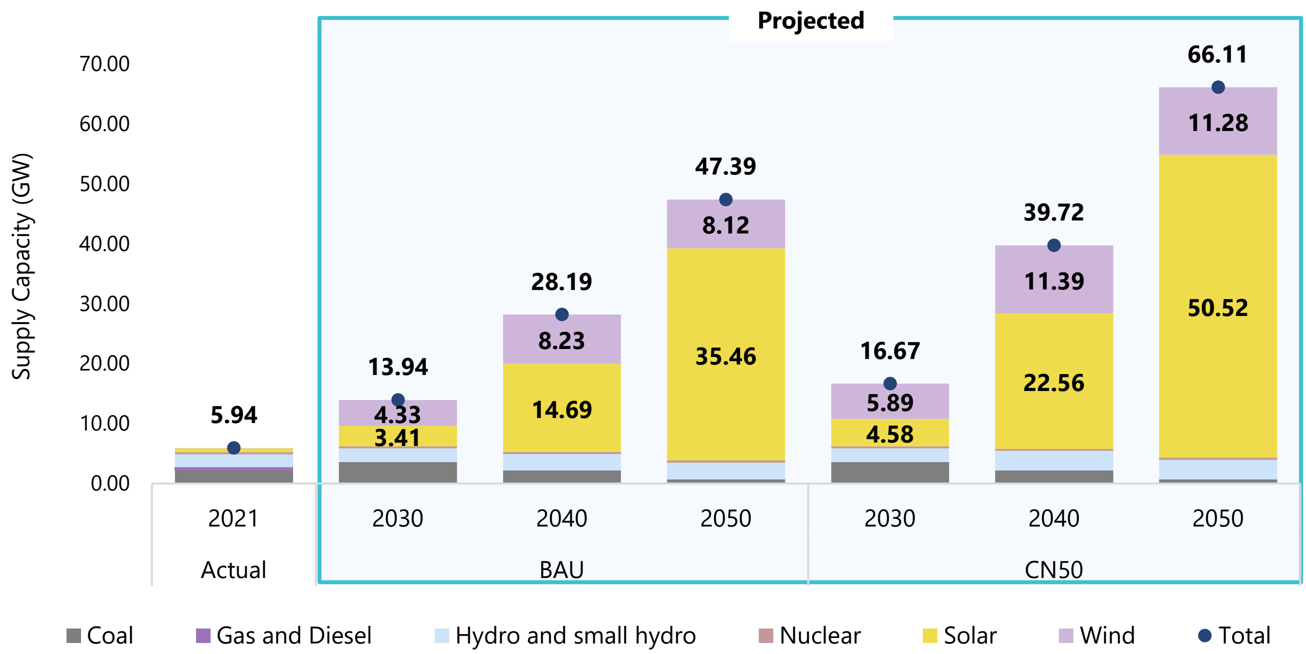


Figure 53: *Electricity Supply capacity mix, BAU and CN50 scenarios*

Note: base year capacity includes the allocated shares in the joint and central share utilities.

The supply capacity required to meet projected demand will expand substantially in both pathways. By 2050, the total non-storage portfolio reaches approximately 47.39 GW in BAU and 66.11 GW in CN50. This surge is primarily driven by the rapid build-out of utility-scale solar, supplemented by significant wind additions and expanding inter-state market procurement capacity.

Under CN50, the required supply capacity reaches 66.11 GW by 2050. Solar expands to 4.58 GW by 2030, 22.56 GW by 2040, and 50.52 GW by 2050. Winds will rise to 5.89 GW in 2030 and 11.28 GW by 2050 (Figure 53).

The increased electrification of industry, transport, and cooking significantly raises the volume of firming energy required outside solar hours, driving higher storage and market procurement investment.

The increased share of RE, particularly Solar, also supports evening demand hours though through energy storage. In CN50, the model builds 21.00 GW of storage capacity with an average supply duration of 8 hours. Whereas in the BAU scenario, the model builds 15.00 GW of energy storage capacity with an average supply duration of 7 hours. In both the scenarios, the energy storage system capacity addition is significantly high and will play a more vital role in non-solar hours to support the demand as well as fulfil the flexibility requirements by 2050.

Generation Mix

In the BAU and CN50 scenarios, renewable energy including large hydro accounts for 95.2% and 96.0% of total electricity generation by 2050, respectively, representing near-complete decarbonisation of the power sector. Solar is the dominant source, supplying 67.03 TWh (approximately 69.80% of total generation) in BAU and 94.59 TWh (72.65%) in CN50 by 2050. Wind contributes 16.79 TWh in BAU and 22.71 TWh in CN50. Hydro provides a further 7.61–7.73 TWh across both pathways.

A residual coal generation of approximately 0.80 TWh (below 1% of total generation) persists due to contractual obligations, while inter-state market procurement supplies 1.51–2.10 TWh annually by 2050.

Coal generation declines significantly in both scenarios. The grid emission factor falls sharply across the planning horizon: under BAU, it declines from approximately 0.58 $kgCO_2/kWh$ in 2021 to around 0.26 $kgCO_2/kWh$ by 2030 and approaches near-zero by 2045. Under CN50, the trajectory is faster, with the grid emission factor approaching near-zero by 2040, consistent with the state's 100% renewable energy ambition. Any residual emission factor in 2050 reflects the small share of coal and market-sourced generation that remains in the portfolio.

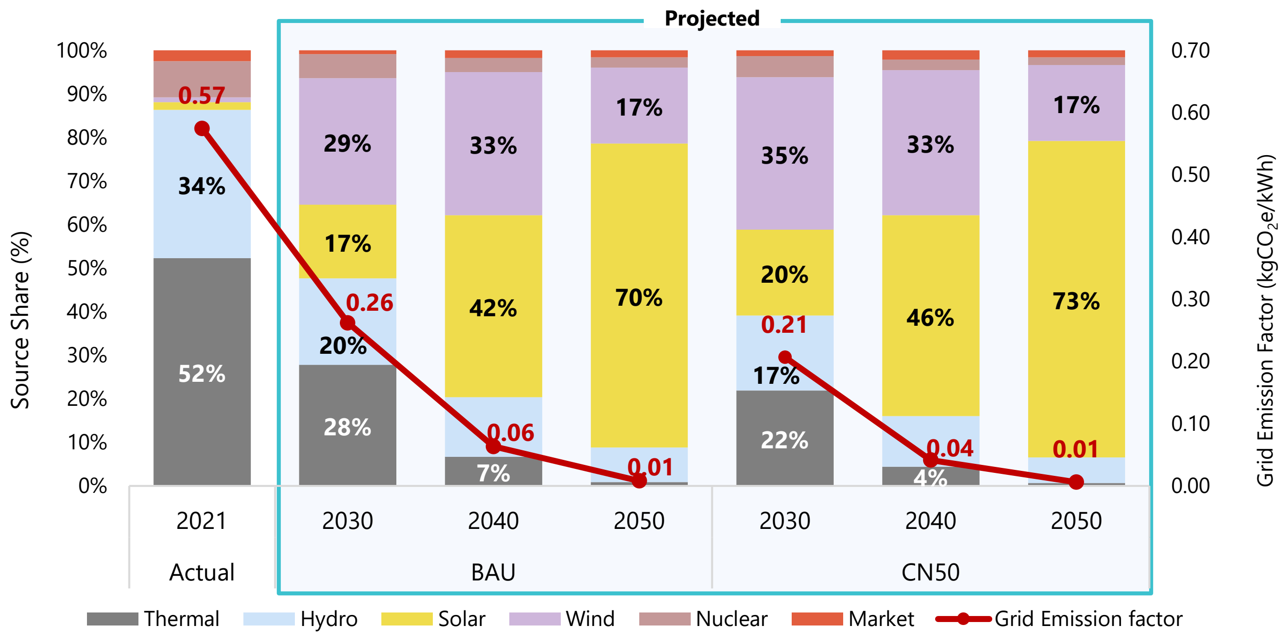


Figure 54: *Generation sources share (%) and grid emissions factor ($kgCO_2e/kWh$), BAU and CN50 scenarios*

Note: base year generation share represents the source share in total power purchase by the KSEB in 2022.

Role of Energy Storage

Battery storage plays an increasingly central role across both pathways. Battery energy capacity rises from 1.90 GWh in BAU 2030 to 38 GWh by 2040 and 105 GWh by 2050, with average storage duration growing from 1 hours in 2030 to 7 hours by 2050. Under CN50, storage scales more rapidly, reaching 63 GWh by 2040 and 153 GWh by 2050, with duration extending to ~8 hours. This transition from short-duration peak-shaving to multi-hour energy shifting reflects the growing role of storage in moving solar surplus from midday into evening and overnight hours as solar penetration deepens.

Battery discharge accounts for 25.89TWh, equivalent to 27.30% of total dispatch, in BAU 2050, and 37.28 TWh (29.47%) in CN50 2050[38]. Dispatch share refers to the contribution of battery discharge to total electricity supplied to the grid. Storage is therefore not merely a reserve or flexibility technology; it becomes a core operational component of the daily power system alongside solar and wind.
In both the BAU and CN50 scenarios, the year-on-year percentage share of storage in dispatch consistently increases, aligning with the growth in renewable energy capacity, particularly solar.

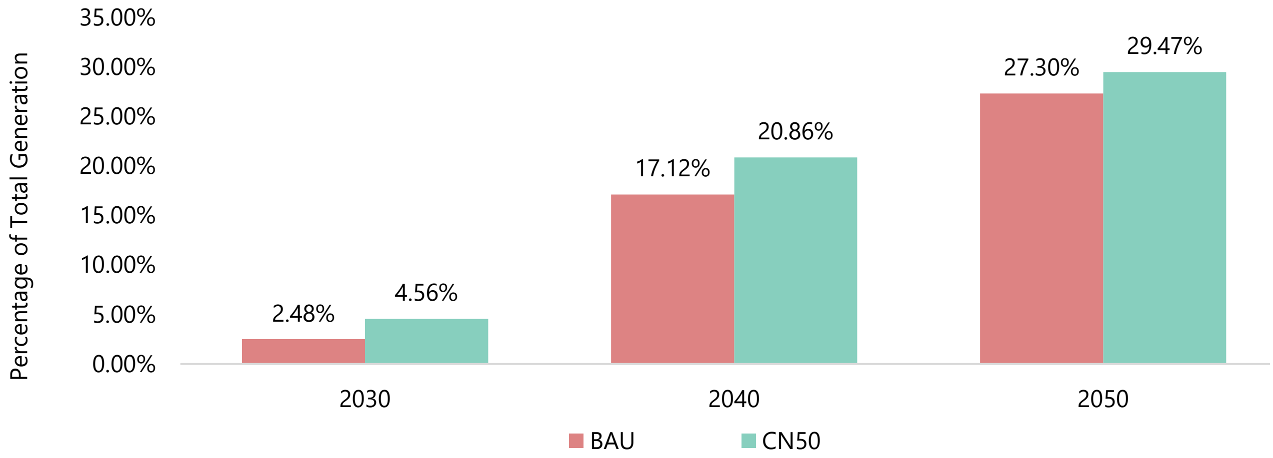


Figure 55: *Share of Energy Storage in Total Electricity Dispatch (%) under BAU and CN50 Scenarios*

Renewable Energy Curtailment

As solar and wind penetration deepens across both pathways, curtailment of available renewable energy becomes a structurally significant issue that requires active planning and policy attention. By 2050, solar curtailment reaches 15.67% in BAU and 16.46% in CN50, implying that roughly one-sixth of available solar energy is spilled rather than delivered or stored. Wind curtailment is considerably higher, reaching 30.40% in BAU and 32.21% in CN50, reflecting the diurnal and seasonal mismatch between wind generation patterns and system demand.

These curtailment levels underscore the importance of co-investing in storage, demand flexibility, and inter-state transmission infrastructure alongside renewable capacity additions. Without adequate storage and grid integration, a growing fraction of installed renewable capacity will be chronically underutilised, eroding both the economic case for continued new additions and the emission

38 Storage capacity estimates include an additional 5% reserve margin for system reliability.

reduction benefits of the transition. Curtailment management is thus not a peripheral concern but a first-order planning priority for Kerala's electricity strategy.

Sensitivity Analysis

Multiple model runs were conducted to assess the impact of key structural assumptions on the capacity mix and system economics. These sensitivity runs are based on the CN50 electricity demand and the overarching objective of achieving 100% renewable energy by 2040.

Each sensitivity scenario alters a single variable while keeping all other assumptions constant as in the CN50 baseline. Three sensitivities are considered, each designed to test a different structural dimension of the transition:

CN50_DS – Peak Demand Shift to Daytime

Shifting the existing late evening demand peak (22:00 hrs) into daytime hours through demand-side management interventions such as time-of-use tariffs, managed electric vehicle charging, flexible industrial loads, and behavioural change. Such a shift better aligns demand with solar generation, reducing the need for long-duration storage and improving solar asset utilisation.

CN50_BESS – Higher BESS Cost

Battery Energy Storage System (BESS) costs are assumed to be **20% higher in all years** compared to the baseline cost trajectory. Since there is a lot of ambiguity on the future cost of the energy storage, particularly the battery energy storage, the study assesses the cost impact on the supply mix.

CN50_NUC – Nuclear Capacity Addition

In line with the national nuclear expansion plan, which targets 100 GW of capacity by 2047, a proportionate allocation has been considered for Kerala. This allocation is based on the State's current share of national nuclear capacity (approximately 5%, 4.85 GW equivalent capacity in 2050), implying a corresponding increase in step with the national build-out.

CN50_UE - Unconstrained Expansion

Although this study primarily assumes the achievement of 100% renewable energy (RE) by 2040, this sensitivity analysis relaxes that constraint and allows the model to build new fossil fuel capacity, if required, to examine the resulting capacity mix. It helps assess, from a purely technology cost perspective, the timeline by which Kerala could achieve 100% RE if not by 2040. Accordingly, the restriction on new coal capacity additions is removed in this scenario, allowing the model to build coal-based generation based on least-cost system optimization.

Results

The overall results from the three sensitivity runs confirm that solar generation coupled with energy storage will continue to meet the majority of electricity requirements in all scenarios. However, the structure of the portfolio, system costs, and the degree of renewable penetration differ materially across cases, highlighting the importance of structural assumptions in transition planning.

Table 29: Contracted Supply Capacity (in GW) across scenario and sensitivities in year 2050

Technology	2021 (Actual)	2050					
		BAU	CN50	CN50_DS	CN50_BESS	CN50_NUC	CN50_UE
Solar	0.65	35.46	50.52	52.82	44.95	35.52	28.18
Wind	0.06	8.12	11.28	9.87	16.02	9.49	17.92
Nuclear	0.37	0.35	0.35	0.35	0.35	4.85	0.35
Hydro and small hydro	2.13	2.76	3.26	3.26	3.26	3.26	3.26
Thermal	2.73	0.70	0.70	0.70	0.70	0.70	1.38
Total capacity	5.94	47.39	66.11	67.00	65.28	53.82	51.08
Energy Storage (GW/GWh)	0	15/105	21/153	20/140	21/127	18 /108	17/63

In **CN50_DS**, solar capacity increases to 52.82 GW by 2050 while wind falls modestly to 9.87 GW, as a larger share of demand is served directly by daytime solar without the mediation of storage. Battery energy capacity falls to 140 GWh, while the renewable share is maintained at 96.0%. This result strongly supports demand-side management and load-shifting as cost-effective complements to supply-side renewable investment.

In **CN50_BESS**, where storage costs are 20% higher, the model substitutes toward wind, which can serve evening demand more directly without storage. Wind capacity rises sharply to 16.02 GW by 2050 – the highest among all scenarios – while solar falls to 44.95 GW and battery energy capacity contracts to 127 GWh with duration at 6 hours.

In **CN50_NUC**, owing to its long operational life and high utilisation, the model builds the entire allocated nuclear capacity of 4.85 GW. This reduces the need for additional solar and storage capacity. Integrating nuclear as a baseload source thus provides a clean option while also lowering the high reliance on solar generation.

In the CN50_UE scenario, where coal capacity additions are unconstrained, the model builds coal capacity in the initial years, up to 2035. However, beyond 2035, the model shifts towards building wind and solar capacity along with storage. The availability of dispatchable coal reduces the need for both solar and storage, with solar capacity declining to 28.18 GW and battery energy capacity contracting to just 63 GWh, less than half of the CN50 baseline. Wind capacity increases to 17.92 GW, the highest among all scenarios, as the model balances variable renewable generation with coal's firm capacity rather than relying heavily on storage. As a result, total system capacity is the lowest at 51.08 GW, reflecting the economic efficiency of retaining coal as a least-cost dispatchable option, especially in the next decade.

Conclusion

Kerala's transition to a near 100% renewable and highly decarbonised electricity system by 2040 is technically feasible, but it requires a fundamental restructuring of how the state plans, procures, and operates its power system. The analysis clearly shows that while Kerala already has a high share of renewables in its installed capacity, it remains structurally dependent on imported coal-based electricity. Bridging this gap will require a rapid scale-up of solar and wind capacity, complemented by large-scale deployment of energy storage and a sustained reliance on inter-state renewable energy trade. Given the state's limited in-state resource potential, external procurement is not a transitional measure but a long-term structural feature of Kerala's electricity system.

The modelling results suggest that solar, supported by storage, will form the backbone of Kerala's future electricity system, with storage evolving into a critical operational asset rather than a supplementary flexibility option. However, the transition also introduces new system challenges, particularly in the form of high renewable curtailment and increased

Solar Panels in Kochi, Kerala

dependence on storage for balancing. These challenges highlight the importance of coordinated investments in grid infrastructure, market mechanisms, and demand-side flexibility.

Further, the sensitivity analysis demonstrates that demand-side interventions such as peak shifting can significantly reduce system costs and storage requirements, reinforcing the need to integrate behavioural and policy measures alongside supply-side expansion.

Finally, the findings emphasise that the pathway to 100% renewable energy is highly sensitive to key structural assumptions, including storage costs, availability of firm low-carbon alternatives, and policy constraints on thermal capacity. While the CN50 pathway targets predominantly renewable electricity system, sensitivity analysis indicates that least-cost optimisation under alternative assumptions may retain a limited role for coal or nuclear under specific scenarios. Achieving the renewable electricity transition by 2040 target will, therefore, require deliberate policy direction and sustained investment support. Kerala's transition is therefore not only a question of technology deployment but also of institutional readiness, regulatory innovation, and long-term planning to ensure a reliable, affordable, and fully decarbonised electricity system.

Kerala Backwaters

Part IV

Green Jobs and Roadmap for People Centric Transition

Chapter 7

Embedding Equity in Kerala's Decarbonisation

Kerala advances towards Carbon Neutrality by 2050 (CN50) through a low-carbon development pathway centred on renewable energy, sustainable mobility, circular economy practices, energy-efficient systems, and climate-resilient agriculture, leading to substantial transformations in employment patterns and the emergence of green livelihood opportunities across sectors.

This transition is expected to generate new opportunities across emerging green sectors while gradually reducing reliance on carbon-intensive activities. The CN50 pathway therefore adopts a 'Just Transition approach', ensuring employment generation, workforce mobility, and social equity, while safeguarding livelihoods accompany that decarbonisation and strengthening resilience across communities.

Employment Transition Dynamics

Kerala's labour market provides a strong foundation for the green transition, supported by high human development indicators, a service-oriented economy, and a decentralised governance system. At the same time, the predominance of MSMEs, a significant informal workforce, and migration-linked income patterns necessitate a carefully managed transition.

Under the CN50 pathway, employment impacts are expected to evolve along three dimensions. New employment opportunities will emerge across clean energy, mobility, waste management, sustainable agriculture, and ecosystem restoration, with strong potential for decentralised job creation.

Simultaneously, certain occupations-particularly those associated with fossil fuel supply chains, internal combustion engine (ICE)-based services, and conventional energy-dependent practices-are expected to decline gradually. While large-scale job losses are unlikely, sectoral and skill-level transitions will require targeted support.

Overall, the employment impact is expected to be net positive. However, potential mismatches in skills, geography, and timing between job creation and displacement highlight the need for proactive workforce transition strategies.

Sectoral Opportunities for Green Job Creation

The transition to a low-carbon economy will create employment opportunities across multiple sectors, driven by structural shifts in energy systems, mobility, and resource use. In the energy sector, the transition towards 100% renewable electricity by 2040 and the projected scale-up of renewable energy capacity to approximately 46-65 GW by 2050 represents a transformative shift. This requirement significantly exceeds the State's estimated in-state renewable potential of around 18-19 GW, making interstate procurement of clean energy a structural necessity. At the same time, the expansion of decentralised energy systems-particularly rooftop solar, behind-the-meter storage, and demand-side management-will create sustained demand for a distributed network of technicians, installers, auditors, and service providers. Leveraging this transition to build decentralised skilling can support the creation of improved localised livelihoods. This transition also establishes decentralised renewable energy systems as a key employment anchor, enabling the development of local technical service ecosystems across the State.

In the transport sector, which accounts for a dominant share of energy-related emissions, the transition towards electric mobility will have significant employment implications. The sector supports a large workforce, predominantly in informal segments, and is heavily dependent on ICE-based systems. The gradual shift away from these technologies will require large-scale reskilling. At the same time, emerging value chains in electric mobility-including manufacturing, charging infrastructure, battery systems, and servicing-will create new employment opportunities and provide scope to enhance inclusivity in a traditionally male-dominated sector. This positions the mobility transition as a critical area for workforce transformation, requiring structured reskilling and enabling the development of new, more inclusive employment pathways.

The decarbonisation of water transport and fisheries will further expand employment opportunities. The electrification of inland vessels, transition to alternative fuels such as green hydrogen for larger vessels, and the gradual electrification of mechanised fishing fleets will create demand for skills in retrofitting, clean energy systems, and maritime services. These interventions also position blue economy activities as emerging areas of livelihood generation aligned with long-term sustainability goals.

In the waste management sector, the expansion of treatment infrastructure and decentralised systems will generate employment in operations, maintenance, and service delivery. Strengthening circular economy practices will further create opportunities in recycling, material recovery, and resource efficiency. The sector thus emerges as a key pillar for circular economy-based livelihoods, driven by decentralised and service-oriented employment models.

In the agriculture sector, the adoption of climate-resilient and low-emission practices will support new livelihood avenues, including agroforestry, organic input systems, and advisory services, reflecting a shift towards more knowledge-intensive production systems. This transition reinforces the role of climate-resilient agriculture as a major source of sustainable and diversified rural livelihoods.

Skills Transition and Workforce Development

The CN50 pathway will require a comprehensive transformation of the State's skill ecosystem to support emerging green sectors. This will involve a combination of reskilling, upskilling, and development of new competencies aligned with evolving technologies.

Reskilling efforts will enable workers in transitioning sectors to move into emerging areas such as renewable energy and electric mobility. Upskilling will enhance adaptability within sectors undergoing technological change, while new skill development will address requirements in areas such as energy storage, hydrogen applications, smart grids, and advanced waste management systems.

The State will align its skill development ecosystem to these emerging needs, ensuring accessibility, quality, and relevance of training programmes. Community-centric delivery approaches will be leveraged to ensure inclusive participation and localised capacity building.

Inclusive and People-Centric Transition

Ensuring equitable distribution of the benefits of the green transition is central to the CN50 pathway. The strategy emphasises inclusive participation, particularly for women, MSMEs, and vulnerable communities.

Women's participation in emerging green sectors will be strengthened through community-centric programmes and local enterprise models, enabling access to new livelihood opportunities. MSMEs will be supported in adopting low-carbon technologies through access to finance, technology support, and capacity building, ensuring competitiveness while aligning with sustainability objectives. This will be critical in enabling a smooth transition of MSMEs and industrial clusters towards low-carbon pathways while sustaining employment and economic resilience.

Institutional Framework for Green Jobs

A coordinated institutional framework will be required to guide and facilitate green job creation under the CN50 pathway. Such a framework should enable convergence across key sectors, including labour, industry, skill development, and local governance, ensuring coherence in planning and implementation.

Given the decentralised governance structure of the State, Local Self Government Institutions will play a critical role in enabling context-specific interventions and supporting the implementation of green job initiatives at the local level.

Kovalam Beach, Kerala

Financing and Implementation Mechanisms

Green job creation under the CN50 pathway will be enabled through convergence of existing programmes, mobilisation of climate finance, and enhanced private sector participation. In addition, there is a need to facilitate the development of new climate-aligned projects and harness emerging mechanisms such as carbon markets and carbon credits, along with the evolving potential of green credit frameworks. Initiatives such as green credit programme can further support ecosystem restoration and other environmentally beneficial activities while generating supplementary income streams and employment opportunities at the community level.

Convergence and aggregation of existing small-scale and decentralised initiatives will be essential to generate the scale required for participation in carbon markets and improve viability of such mechanisms. Skill development, enterprise promotion, and livelihood initiatives will be aligned with the low carbon transition to facilitate the scaling of green employment opportunities.

Public-private partnerships will play an important role in expanding opportunities in sectors such as renewable energy, electric mobility, and waste management. Innovative financing approaches will also support entrepreneurship and enterprise development in emerging green sectors.

Financial mechanisms will be designed to ensure inclusive access, particularly for low-income and vulnerable groups, and not be limited to formal enterprises. Instruments such as concessional finance, risk-sharing mechanisms, and viability gap support can enable wider adoption of clean technologies across decentralised and livelihood-linked sectors, thereby supporting broader participation in green employment opportunities.

These approaches will focus on improving affordability and accessibility, while remaining responsive to local needs and enabling community-level participation, thereby strengthening the inclusiveness and effectiveness of the transition.

Kochi Water Metro, Kerala

Part V

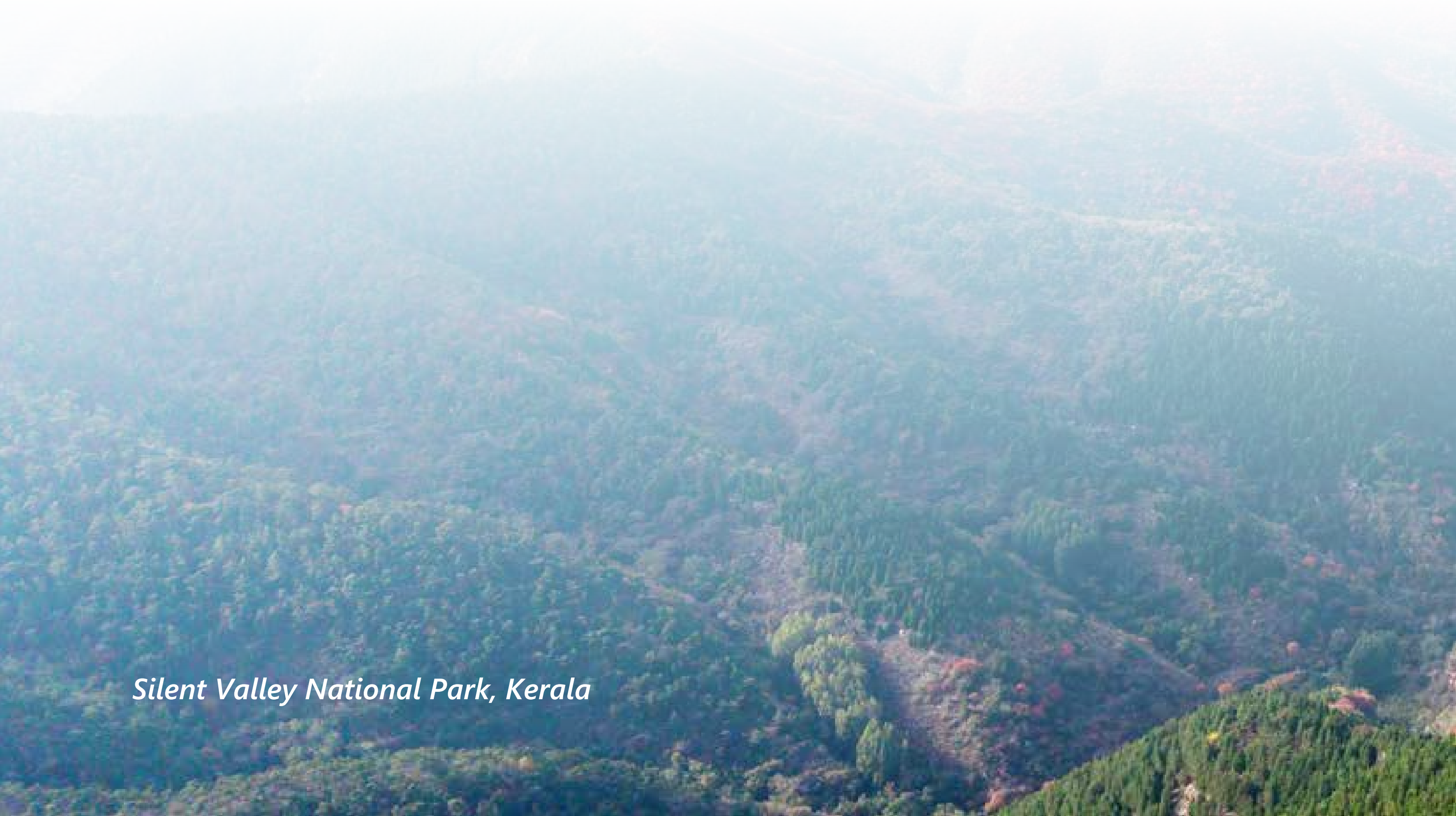
Way Forward

Way Forward

The Carbon Neutral Kerala 2050 (CN50) pathway provides a strategic framework to guide the State's transition towards low-carbon and climate-resilient development. Its implementation will require coordinated action across sectors, alignment of existing institutional, financial, and planning systems, and sustained engagement across stakeholders, while retaining flexibility to respond to emerging technologies and evolving development priorities.

A coordinated approach across departments and sectors will be essential to ensure alignment and effective implementation. Sectoral departments will play a primary role in designing and executing interventions within their respective domains, supported by integration with existing planning processes and ongoing programmes. Implementation will follow a sector-led, decentralised approach, wherein local governance systems enable context-specific planning and facilitate on-ground execution, particularly for decentralised interventions across sectors such as energy, mobility, waste management, and ecosystem restoration.

Mobilisation and alignment of finance will be critical to support the transition, including leveraging public finance, enabling access to climate finance, and facilitating private sector



Silent Valley National Park, Kerala

participation. In this context, developing a pipeline of new climate-aligned projects and effectively utilising market-based mechanisms such as carbon credits will be important. Convergence and aggregation of existing small-scale and decentralised initiatives can enable the generation of scale required for participation in carbon markets, thereby improving financial viability and supporting broader engagement across sectors. Financial approaches will aim to improve access and affordability, particularly for decentralised and livelihood-linked interventions, thereby enabling broader participation in emerging economic opportunities.

The transition will be driven across key emitting sectors, supported by alignment of existing mechanisms to facilitate adoption of low-carbon and resource-efficient practices, along with access to finance, technical support, and capacity building. An enabling ecosystem for technology adoption and innovation will further be strengthened through improved linkages between research, industry, and implementation systems to support effective deployment and diffusion of low-carbon solutions.

Strengthening the State's skilling ecosystem will be important to support workforce readiness across emerging sectors, while capacity building within government institutions and local bodies will enable effective planning, implementation, and monitoring. The transition will require a whole-of-government and whole-of-society approach, with active participation from sectoral departments, local bodies, private sector entities, financial institutions, research organisations, and communities.

A robust approach to monitoring and review will be essential to track progress and guide decision-making, with periodic refinement of strategies to ensure continued alignment with technological, economic, and policy developments. Kerala's institutional strengths and decentralised governance framework provide a strong foundation to operationalise this pathway, positioning the State as a model for integrated and inclusive low-carbon development.

Annexes

Annexure 1: Current Policy Context in the State

Table below presents the key policy highlights implemented within the state of Kerala, driving future investments and directing government focus towards critical end-use areas. This facilitates our understanding of the state's future energy mix.

Sl. No.	Policy	Key Highlights of the Policy
1.	**Kerala Industrial Policy, 2023**	a. Focus on EV Manufacturing b. Electronics Park development. c. Development of Advanced Rubber products and export facility
2.	**Kerala Solar Energy Policy, 2013**	a. Increase installed solar capacity in the State to 500 MW by 2017 b. Achieve 2500 MW installed solar capacity by 2030 c. Promotion of Solar Water Heating System and Solar Steam Systems in domestic, commercial and industrial spaces. d. Solar installations in public buildings e. Installation of rooftop solar power systems, including solar inverter installations, solar powered cellular towers, etc f. Off-site generation on canals, reservoirs (floatovoltaic), waste lands, quarries, etc.
3.	**Kerala Power Policy, 2019**	a. State renewable energy goal by 2022 is 1970 MW, with 1870 MW coming from solar. b. Development of grid-level energy storage systems. c. Deployment of floating solar plants d. Focussing on the waste to energy projects.
4.	**Agricultural Development Policy, 2015**	a. Development of energy efficient dewatering devices. b. Installation of solar, wind and hybrid technology to minimise the power consumption and cost of cultivation. c. Development of windmills for electricity generation for agricultural production activities d. Use of biogas from the agricultural waste into electricity generation
5	**Electric Vehicle Policy**	a. 1 million EV on road by 2022 b. Pilot fleet of 200,000 2W, 50,000 3W, 1000 goods carriers, 3000 buses, and 100 ferry boats. c. Availability of adequate charging infrastructure in major cities and on highways and major roads.

Sl. No.	Policy	Key Highlights of the Policy
		d. Exemption of road tax on EV for the initial 3 years. e. Promotion of local manufacturing of EV components/ vehicles. f. Focus on awareness creation and promotion through EV expo and E-mobility zones.
6	**Kerala Renewable Energy Policy, 2002**	a. Mandatory use of Fluorescent and Compact Fluorescent Lamps (CFL) in all new Hospitals, Hotels, Government Offices, and offices of PSUs. b. Replace current incandescent lamps with Fluorescent and Compact Fluorescent Lamps with prescribed quality within 2 years of policy initiation. c. Industries with 2000 kVA and above must generate 5% of their energy from renewable sources using captive power plants. d. Energy-efficient devices like Improved Community Chulhas required in hotels, hostels, schools with meal schemes, and industries using firewood. e. Mandatory solar water heating in lodges, hotels (≥10 rooms), and hospitals (≥20 beds). f. Choice of green pricing
7	**Kerala Small Hydro Power Policy, 2012**	a. Increase Small Hydro Power Projects' contribution to State installed capacity from 145 MW to approximately 295 MW by 2017 through private participation. b. Small hydro power projects will be assigned to private developers through competitive bidding under the Build Own Operate Transfer (BOOT) mode for 30 years, after which they will be transferred to the government at no cost.
8	**Kerala State Electricity Regulatory Commission (Renewable Energy & Net Metering) Regulations, 2020**	a. Renewable energy purchase obligation for obligated entities. b. Procurement of Renewable Energy Certificates to fulfil Renewable Purchase Obligation
9	**Kerala Energy Conservation (Building Code) Rules, 2017**	a. Aims to achieve energy neutrality in commercial buildings. b. Provides design norms for thermal performance requirements for walls, roofs, and windows, as well as daylighting, lamps, and luminaire performance requirements

Sl. No.	Policy	Key Highlights of the Policy
10	**Urja Kerala Mission**	a. Soura Project: i. Establish 1000 MW of solar power capacity in Kerala within 3 years, comprising 500 MW from rooftop solar installations across residential, public, and commercial buildings, including schools, hospitals, and commercial establishments. ii. Implement rooftop domestic grid-connected solar power plants with capacities ranging from 2 kW to 10 kW for individual consumers and up to 500 kW for housing welfare societies, totaling a minimum aggregate capacity of 25 MW. a. Filament-Free Kerala project: ii. Replacement of filament bulbs with LED lamps for residential and street lighting. iii. Distribute 7.5 crore LED bulbs and 3.5 crore LED tubes. c. TransGrid 2.0 project: i. Strengthening of transmission network and reduction of Transmission and Distribution (T&D) losses. ii. Implementation to ensure uninterrupted power supply till 2040 in two phases: Rs. 2711 Crore for Phase I and Rs. 3630 Crore for Phase II. iii. Construction of three 400 kV substations, 22 220 kV substations, one 110 kV substation, and 3670 circuit km of extra high voltage lines.
11	**Green Income Initiative**	a. Installation of 2kW solar power plant enabling 300 homes and 3kW solar power plants for 100 homes.
12	**Kerala draft green hydrogen policy**	a. Achieving a green hydrogen production capacity of 5 million metric tonne by 2030. b. Target 30% green hydrogen blending by 2027 in fertilizer, refinery, and chemical sectors. c. CAPEX subsidy of 25% for the first 100 MW electrolyser capacity, plus cost reduction to ₹200/kg by 2030. d. Develop a Hydrogen Valley Innovation Cluster and a major Green Hydrogen Hub in Kochi (₹18,500+ crore investment). e. Pilot projects for hydrogen trucks, refuelling stations, and positioning Kerala as a green hydrogen export hub through ports.

The table below presents the key policy highlights implemented within the state of Kerala, for the Agriculture, Water and Waste sectors.

Sl. No.	Policy	Key Highlights of the Policy
1	**Nava Keralam Mission**	a. Vision: Execute the unified "Water, Cleanliness, Harvest" framework to rejuvenate over 51,700 km of water networks and scale carbon-neutral agricultural practices. b. Prevention of water source pollution: Enforce the Kerala Municipality (Amendment) Act 2024 to mandate source-level waste segregation and apply non-bailable penalties for polluting water resources. c. Carbon Auditing: Institutionalise decentralised carbon auditing through the Net Zero Carbon Kerala campaign to track and achieve specific neutrality targets by 2050. d. Carbon Neutral Goshree Pilot: Implement the state's first island-based net-zero roadmap in eight grama panchayats, utilising carbon emission surveys and mangrove-based sequestration as a model for 2050 neutrality. e. Malinya Muktham Strategy: Implement decentralised septage treatment and 100% door-to-door collection via the Haritha Karma Sena to eliminate methane from landfills.
2	**Kerala State Organic Farming Policy, 2010**	a. Shift from carbon-intensive synthetic pesticides and chemical fertilisers to organic farming practices. b. Implement organic farming in the state in a phased manner c. Prioritising the cultivation of indigenous seed varieties and strengthening agro-biodiversity.
3	**Agricultural Development Policy, 2015**	a. Watershed-Centric Planning: Mandates the watershed as the primary natural unit for all agricultural development to integrate soil, water, and crop management into one cohesive plan. b. Bio-Manure Institutionalisation: Prioritises state-wide production of bio-manure and bio-fertilisers to rebuild soil health, including a financial bridge for farmers during the transition to organic practices. c. Climate-Resilient Precision Farming: Precision systems shield crops from extreme weather spikes to prevent total harvest failure. This controlled setup blocks pests naturally, eliminating the heavy chemical pesticide loads that degrade soil biology.

Sl. No.	Policy	Key Highlights of the Policy
4	**Ecorestoration Policy, 2021**	a. Natural Forest Restoration: Convert degraded forests and failed plantations into native natural forests while removing invasive species to aid native growth. b. Digital Boundary Protection: Prevent encroachment through scientific demarcation, digitisation, and updated revenue records for all forest lands. c. Coastal Bio-Shields: Establish "Theeravanam" (coastal forests) and restore mangrove ecosystems through local participation to ensure shoreline stability. d. Community-Led Conservation: Foster diverse livelihood opportunities for forest-dependent communities through decentralised public participation in restoration projects. e. Circular Waste & Pollution Control: Implement state-wide bans on single-use plastics and strengthen integrated coastal zone management to protect ecosystems from non-biodegradable waste.
5	**Tree Banking & Private Land Incentivization (2025 Update)**	a. Private Carbon Offsetting: Incentivizes tree planting on private lands to support state-wide carbon neutrality and timber self-sufficiency. b. Long-Term Cash Support: Provides annual financial incentives (₹10–₹30 per tree) for up to 15 years to landowners for tree retention. c. High-Value Timber Access: Supplies free seedlings of 10 species (e.g., Sandal, Teak) and allows private felling/sale under the 2026 Forest Act. d. Verified Offsets: Mandates GPS geotagging and monitoring of individual trees to ensure accurate carbon auditing and incentive disbursement.
6	**Kerala State Environment Policy Framework (introduced in 2009 and later updated through SAPCC 2.0 & K-SBSAP)**	a. Biodiversity Mainstreaming: Implementing the Kerala State Biodiversity Strategy and Action Plan (K-SBSAP) 2025–2035 to institutionalise conservation across all sectors and transform Kerala into India's most biodiverse-friendly state b. Climate Justice: Prioritising equitable resource access and resilience for marginalised communities as mandated by the State Action Plan on Climate Change 2.0. c. Results-Based Green Budgeting: Financing ecosystem restoration through the specialised Environment Budget to track the precise ecological impact of state spending.

Sl. No.	Policy	Key Highlights of the Policy
7	**Sewerage schemes of the state, KWA Thiruvananthapuram Sewerage Scheme (TSS), and Kochi Sewerage Scheme(KSS)**	Aims to develop a comprehensive and sustainable sewage and septage management system for the entire state of Kerala to protect the environment and public health
8	**Rebuild Kerala Initiative**	a. Agro-Ecological Realignment: Mandate the transition of agriculture into five specialised zones to promote carbon-neutral, disaster-resilient crop varieties tailored to localised climate risks. b. Landscape-Scale Forest Restoration: Prioritise the conversion of 20,000 hectares of monoculture plantations back to natural forest ecosystems and reclaim abandoned mines to maximise carbon sinks. c. Integrated Wetland & Coastal Protection: Enforce strict conservation for the state's Ramsar sites and notified wetlands to preserve their natural flood buffering and carbon sequestration capacity.

Annexure 2: Difference between Centralised Treatment, Onsite Treatment, and FSTP for Domestic Wastewater

	Centralized treatment	Onsite treatment	FSTP
Definition	Centralised wastewater treatment includes primary, secondary, and tertiary treatment. In primary treatment, physical barriers remove larger solids from the wastewater. Remaining particulates are then allowed to settle. Secondary treatment consists of a combination of biological processes that promote biodegradation of wastewater constituents	On-site treatment system of domestic sewage, consisting of two or more compartments, in which the sanitary flow is detained to permit concurrent sedimentation & sludge digestion. • A septic system includes a septic tank (buried) and a soil dispersal system. • Solids and dense materials in wastewater settle as sludge in the tank and floatable material (scum) is also retained in the tank.	An independent faecal sludge and septage treatment facility for remediating the solid and liquid components to prescribed standards for safe disposal and reuse.

	Centralized treatment	Onsite treatment	FSTP
	by microorganisms. The treatment processes include aerobic stabilisation ponds, trickling filters, and activated sludge processes, as well as anaerobic reactors and lagoons. Tertiary treatment processes are used to further purify the wastewater of pathogens, contaminants, and remaining nutrients such as nitrogen and phosphorus compounds. This is achieved using one or a combination of processes that can include maturation/ polishing ponds, biological processes, advanced filtration, carbon adsorption, ion exchange, and disinfection Sludge is produced in all of the primary, secondary and tertiary stages of treatment and a stand alone sludge treatment/stabilization is necessary. May produce limited CH_4 from anaerobic pockets. Plants with nutrient removal processes are sources of CH_4 and N_2O.	• Sludge undergoes anaerobic digestion at the tank bottom. Liquid remains in the tank for 24-72 hours, depending on tank volume and hydraulic load • Partially treated water is discharged into the dispersal system. • Solids accumulate and degrade anaerobically over several years and Solids retention time (SRT) depends on sludge withdrawal frequency. • Anaerobic sludge digestion produces gases (mainly CH_4 and biogenic CO_2) that rise and are released through vents. • Gases from the effluent dispersal system (mainly N_2O and biogenic CO_2) are released through the soil. • Pit latrines are lined or unlined holes of up to several metres deep, which may be fitted with a toilet for convenience. The pits are used alternatively, and the contents used as manure. • Anaerobic conditions favourable to CH_4 emissions occur when the water table is high and the organic waste in the pit is submerged.	Sludge Drying Beds Treatment: • Septage from the screening chamber goes to Sludge Drying Beds for dewatering and drying. • Percolate liquid drains out, and sludge dries by evaporation in 8-12 days. • Sludge with 30-40% moisture content can be further treated or disposed of. Sludge Percolate/Liquid Treatment in ABR: • Filtrate from drying beds treated in Anaerobic Baffled Reactor (ABR). • Active biomass degrades organic matter as liquid passes through. Planted Gravel Filter (PGF) Treatment: • Liquid from ABR is further treated in gravel-filled basins with wetland vegetation. • Filter removes particles, microorganisms degrade organics and provides surface for bacteria, vegetation helps maintain oxygen levels for aerobic bacteria.

	Centralized treatment	Onsite treatment	FSTP
			Disinfection Unit + Treated Water Collection Tank: • Electro Chlorinator or Chlorine dosing unit used for disinfection. (Chlorination ensures disinfection before disposal or reuse)
Population density	Suitable for high density population centres	Suitable for low density area	Suitable for high density population centres
	Requires UGD connection	Requires desludging every 2-5 years depending on the usage through a sludge evacuation truck	
BOD removal efficiency	50-90%	20-40%	>80%
Options	Several treatment technologies such as oxidation pond, activated sludge process, anaerobic treatment, moving bed biofilm reactor, etc are available. The choice is based on space availability, cost, maintenance, treatment efficiency	Usually a single pit/ two pit or recently holding tank based chamber wherein the settleable solids settle and the clear untreated wastewater is let t percolate in the ground and get treated naturally through filtration	Several technologies for sludge treatment such as aerobic sludge stabilization, anaerobic sludge digesting with methane recovery are available.
Manpower for regular operation and maintenance	Required	Not required	Required
Energy requirement	Energy intense	No energy required	Energy intense

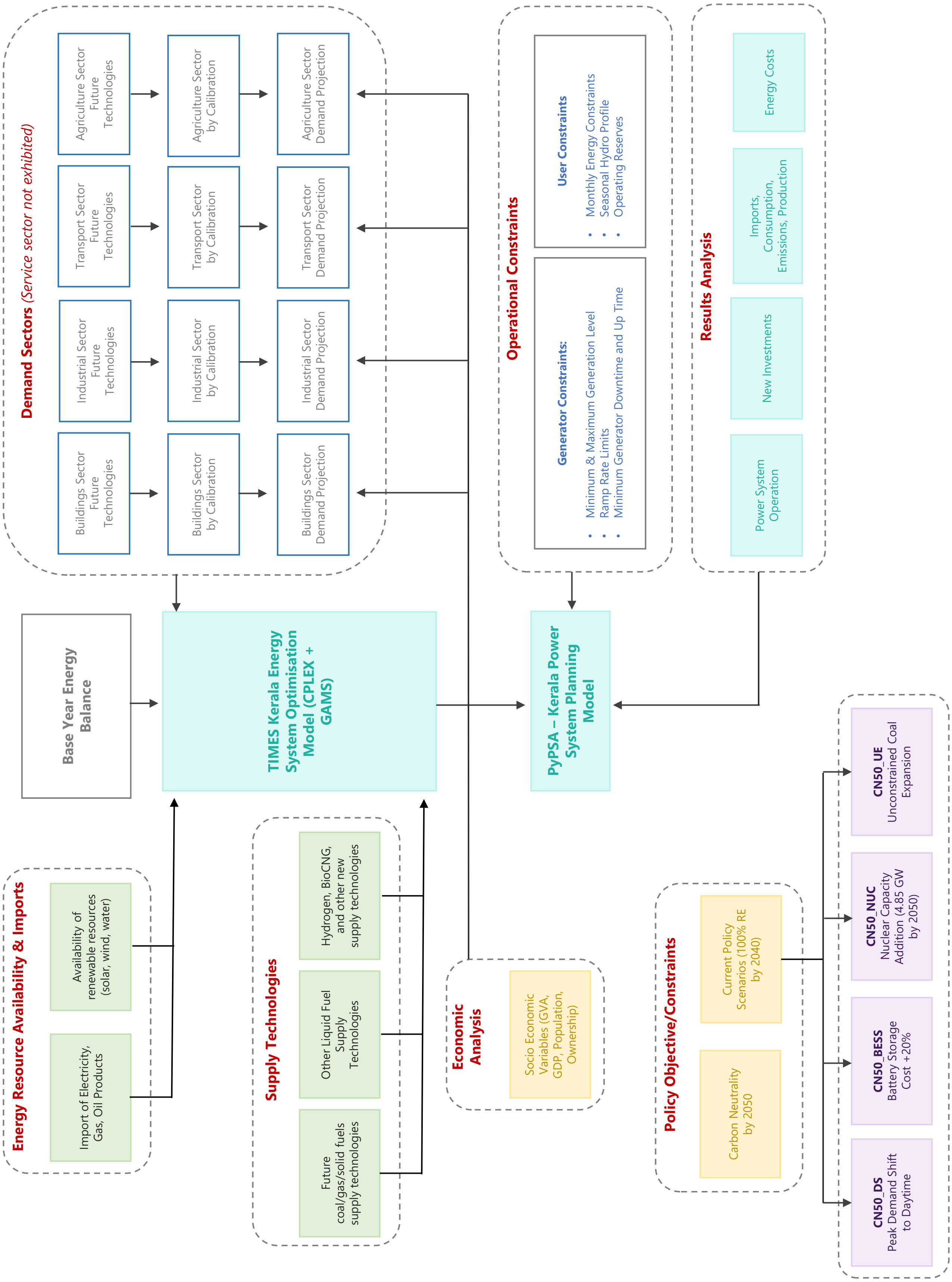
Annexure 3: Assumptions on Operational and financial parameter of electricity generating sources, in BAU and CN50

Technology	Capital cost (Rs Crore/MW)		Variable cost (Rs/kWh)		Plant Life	Normative CUF	Startup / Shut down cost (Rs./kW)	FOM (Rs./kW)
	2025	2050	2025	2050				
Solar (inside/ outside)	4/4	3.1/3.1	-	-	25	0.22	-	400
Wind (inside/ outside)	9/7.5	9/6.5	-	-	25	0.29	-	750
Coal*	11.5	11.5	2.6	5.4	25	0.85	14.14	1950
Nuclear	14	14	-	-	40	0.80	-	2700
Hydro	9	9	-	-	40	0.43	-	2250
Biomass	5.7	5.7	3.4	3.9	-			400
Battery Storage	1.13	0.66	-	-	15	-	-	133
Pump Storage	10	7	-	-	40			5000

Source: Authors' Compilation based on CEA technology catalogue and other publications (Government of India (B), December 2025)

*Including pollution control equipment (PCE) cost

Annexure 4: TIMES Energy Modelling Framework



Annexure 5: Energy Unit Conversions

Carrier / Product	From Unit	To Unit	Conversion Factor
Natural Gas	1 MMBtu	SCM	25.2 SCM
	1 SCM	MMBtu	0.03966 MMBtu
	1 SCM	Kg	0.76 Kg
	1 MMSCM	MMBtu	39,660 MMBtu
Energy	1 kWh	MJ	3.6 MJ
	1 litre Gasoline	MJ	34.2 MJ
	1 litre Diesel	MJ	38.6 MJ
Crude Oil / Petroleum	LPG	kJ/kg	47,300 kJ/kg
	LPG	toe/Metric Tonne	1.130 toe/tonne
	Diesel Oil (HSD+LDO)	kJ/kg	43,334 kJ/kg
	Diesel Oil (HSD+LDO)	toe/Metric Tonne	1.035 toe/tonne
	Fuel Oil	kJ/kg	41,240 kJ/kg
	Fuel Oil	toe/Metric Tonne	0.985 toe/tonne
	Petrol/Motor Spirit	kJ/kg	44,800 kJ/kg
	Petrol/Motor Spirit	toe/Metric Tonne	1.070 toe/tonne
	ATF	kJ/kg	44,600 kJ/kg
	ATF	toe/Metric Tonne	1.065 toe/tonne

Annexure 6: Capacity Mix under Different Scenarios

		Coal	Nuclear	Hydro	Solar	Wind	Storage (GWh)
CN50_NUC	2030	3.60	0.72	2.26	4.15	5.24	3.40
	2040	2.16	2.35	3.26	17.82	9.60	46.80
	2050	0.70	4.85	3.26	35.52	9.49	107.80
BAU	2030	3.60	0.37	2.26	3.41	4.33	2.0
	2040	2.16	0.35	2.76	14.69	8.23	37.90
	2050	0.70	0.35	2.76	35.46	8.12	105.20
CN50_DS	2030	3.60	0.37	2.26	5.41	5.13	2.30
	2040	2.16	0.35	3.26	24.44	9.99	61.10
	2050	0.70	0.35	3.26	52.82	9.87	140.50
CN50	2030	3.60	0.37	2.26	4.58	5.89	4.20
	2040	2.16	0.35	3.26	22.56	11.39	63.30
	2050	0.70	0.35	3.26	50.52	11.28	152.70
CN50_BESS	2030	3.60	0.37	2.26	4.22	6.34	2.30
	2040	2.16	0.35	3.26	19.70	15.54	46.90
	2050	0.70	0.35	3.26	44.95	16.02	126.80
CN50_UE	2030	3.84	0.37	2.26	4.11	3.20	1.60
	2040	3.20	0.35	3.26	11.07	14.34	7.42
	2050	1.38	0.35	3.26	28.18	17.92	63.00

Annexure 7: Kerala CN50 Pathway Network

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1	Dr. K. Rajendran	Director	Institute for Climate Change Studies (ICCS)
2	Dr. Samson Mathew	Director	National Transportation Planning and Research Centre (NATPAC)
3	Sri. Sarath Winston Aravind	Director, Kerala Coffee Limited	AG&P (Think Gas)
4	Sri. Jeeva Anandan	Director	Kerala Coffee Limited
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8	Dr. Jisha S	Principal Scientific Officer	Kerala State Biodiversity Board
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11	Sri. Johnson Daniel	Head (NMEEE & DSM) Division	Energy Management Centre Kerala
12	Smt. Sreetha.T	CEO (Project Cell), incharge of AD (SMS) Dairy	Dairy Development Department
13	Er. Krishnan M. N.	Chief Environmental Engineer	Kerala State Pollution Control Board
14	Dr. Roy Stephen	Associate Director of Research	Kerala Agricultural University (KAU)
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S. No.	Name	Designation	Department/ Organisations/Institution
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23	Sri. Amruth Raj	Executive Engineer (purchase)	Kerala Water Authority
24	Sri. Shibu	Manager (Maintenance & Works)	Kerala State Road Transport Corporation (KSRTC)
25	Dr. Shijo Joseph	Assistant Professor & Coordinator, CCREM	Kerala University of Fisheries and Ocean Studies (KUFOS)
26	Sri. George Ajay	Superintendent	Kerala Shipping and Inland Navigation Corporation
27	Sri. Mohanan J	Technical Manager, Nodal Officer	Agency for New and Renewable Energy Research and Technology (ANERT)
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33	Sri. Deepu D	Assistant Director	Directorate of Industries & Commerce
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40	Dr. Vinod John	Deputy Director	Directorate of Animal Husbandry
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44	Smt. Leaya Jose	Assistant Director of Agriculture	Directorate of Agriculture Development and Farmers welfare
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52	Dr. S. Sandeep	Sr. Scientist	Kerala Forest Research Institute (KFRI)
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57	Smt. Jisha Albert	Executive Engineer (FEMU)	Kerala State Electricity Board (KSEB)
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71	Sri. Rijesh N M	Town Planner	LSGD
72	Sri. Jagajeevan N	Consultant	LSGD
73	Sri. Geojan Antony	Deputy Town Planner	LSGD
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77	Smt. Chithra K M	Asst. Manager (Products)	Kerala Co-Operative Milk Marketing Federation
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82	Smt. Rini D H	Associate Director	Vasudha Foundation
83	Smt. Resmi K S	GIS Specialist	Directorate of Environment and Climate Change
84	Sri. Dileep R	Chief General Manager	FACT


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STATE CLIMATE ACTION NETWORK
Stakeholder Consultation on SAPCC Stocktaking &
Kerala Carbon Neutral Pathway 2050
11 March 2026, Hotel Dimora, Thiruvananthapuram
DIMORA

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NOTES

DIRECTORATE OF ENVIRONMENT
AND CLIMATE CHANGE
Department of Environment
Government of Kerala

DIRECTORATE OF ENVIRONMENT AND CLIMATE CHANGE (DoECC)

The Directorate of Environment and Climate Change (DoECC) under the Environment Department was constituted in December 2010. The Directorate is the nodal agency in the administrative structure of the Environment Department, responsible for planning, promoting, and coordinating the implementation of both Central and State level environmental protection and conservation policies and programs. The Directorate also serves as the nodal agency in formulating climate change-related policies, plans, programmes and their execution. The State Climate Change Cell (CCC) constituted vide G.O. (Rt) No. 27/2018/Envt dated 24-02-2018 in the Directorate coordinates all State-level programs concerning climate change.

VASUDHA FOUNDATION
Green ways for a good earth!

VASUDHA FOUNDATION

Vasudha Foundation, a non-profit organization set up in 2010, is one of the prominent Think Tanks with the mission to conserve the environment through innovative approaches that can ensure a sustainable and inclusive future for India. Its mission is to promote environment-friendly, socially just and sustainable models of energy by focusing on renewable energy, energy-efficient technologies and lifestyle solutions. Vasudha Foundation's approach is largely data-driven analysis, creation of cross-sectoral data repositories along with strategic outreach to ensure resource conservation with the ultimate objective of conserving Mother Earth.

Vasudha Foundation has engaged actively with various organizations and agencies at both the national level and the State level and has forged many active partnerships. These include NITI Aayog, CAG, BEE, MNRE, and MoEFCC at the national level and state governments including Kerala, Assam, Gujarat, Madhya Pradesh, Maharashtra, Odisha, Tamil Nadu, Uttar Pradesh, UT of Jammu & Kashmir and UT of Ladakh to name a few.

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