सत्यमेव जयते
NITI Aayog

A STUDY REPORT ON

Scenarios Towards Viksit Bharat and Net Zero: An Overview

(VOL. 1)

NITI Aayog
Government of India,
Sansad Marg, New Delhi–110001, India

Suggested Citation

NITI Aayog. (2026). A Study Report On - Scenarios Towards Viksit Bharat and Net Zero: An Overview (Vol. 1).

Available at: https://niti.gov.in/publications/division-reports

Disclaimer

1. This document is not a statement of policy by the National Institution for Transforming India (hereinafter referred to as NITI Aayog). It has been prepared by the Green Transition, Energy, Climate, and Environment Division of NITI Aayog under various Inter-Ministerial Working Groups (IMWGs) constituted to develop Net-Zero pathways for India.
2. Unless otherwise stated, NITI Aayog, in this regard, has not made any representation or warranty, express or implied, as to the completeness or reliability of the information, data, findings, or methodology presented in this document. While due care has been taken by the author(s) in the preparation of this publication, the content is based on independently procured information and analysis available at the time of writing and may not reflect the most current policy developments or datasets.
3. The assertions, interpretations, and conclusions expressed in this report are those of the author(s) and do not necessarily reflect the views of NITI Aayog or the Government of India, unless otherwise mentioned. As such, NITI Aayog does not endorse or validate any of the specific views or policy suggestions made herein by the author(s).
4. NITI Aayog shall not be liable under any circumstances, in law or equity, for any loss, damage, liability, or expense incurred or suffered as a result of the use of or reliance upon the contents of this document. Any reference to specific organisations, products, services, or data sources does not constitute or imply an endorsement by NITI Aayog. Readers are encouraged to independently verify the data and conduct their analysis before forming conclusions or taking any policy, academic, or commercial decisions.

सत्यमेव जयते

NITI Aayog

A STUDY REPORT ON

SCENARIOS TOWARDS VIKSIT BHARAT AND NET ZERO: AN OVERVIEW

(VOL. 1)

सुमन के. बेरी
उपाध्यक्ष
SUMAN K. BERY
VICE CHAIRMAN

Phones : 23096677, 23096688
Fax : 23096699
E-mail : vch-niti@gov.in

सत्यमेव जयते

भारत सरकार
नीति आयोग, संसद मार्ग
नई दिल्ली - 110 001
Government of India
NATIONAL INSTITUTION FOR TRANSFORMING INDIA
NITI Aayog, Parliament Street,
New Delhi - 110 001

FOREWORD

Hon'ble Prime Minister has articulated a clear and ambitious vision of India becoming a Viksit Bharat by 2047. This vision goes beyond economic size to encompass a fully developed society, marked by improved quality of life, inclusive growth, strong infrastructure, technological capability, and sustained progress across health, education, skills, and equity. It calls for a more productive and resilient growth model aligned with the aspirations of India's citizens.

India's development journey is unfolding in a complex global environment marked by geopolitical uncertainty, volatile energy markets, and uneven progress on climate action. At the same time, the Hon'ble Prime Minister's Panchamrit commitments have placed India on a clear path towards climate responsibility. Pursuing rapid economic growth alongside a transition to net zero emissions is therefore not a choice but a necessity. This makes India's pathway distinctive, as few countries have sought to raise living standards at this scale while simultaneously transforming their energy systems and industrial structures.

India's circumstances add further complexity. Despite contributing less than four per cent of cumulative global emissions and having per capita emissions well below the global average, the country remains highly vulnerable to climate risks. Development, poverty reduction, and job creation continue to be overriding priorities, even as climate impacts intensify. Understanding how India can meet its development objectives while steadily reducing emissions is therefore central to long term policymaking.

It is in this context that NITI Aayog constituted ten Inter-Ministerial Working Groups to examine sectoral and cross-cutting dimensions of India's development and energy transition. These groups brought together policymakers, domain experts, and industry stakeholders to assess pathways across power, industry, transport, buildings, agriculture, and waste, as well as issues relating to finance, critical minerals, macroeconomic impacts, employment, and equity.

This synthesis report titled, "*Pathways to Net Zero - Towards Viksit Bharat and Net Zero: An Overview*" integrates their findings into a comprehensive national assessment covering the medium term to 2050 and the long term to 2070. The analysis demonstrates that India can sustain rapid economic growth while progressively decoupling it from energy use and emissions. Even as the economy expands sharply, improvements in efficiency, electrification, and the circular use of materials lead to significant reductions in energy intensity. Under the net zero pathway, final energy demand by 2070 is substantially lower than under a continuation of current policies, despite much higher levels of income, urbanisation, and industrial output. These outcomes underline the importance of demand-side measures and development choices that reduce long-term resource intensity.

Contd/....

The transition is anchored in a decisive shift towards electricity and non-fossil energy. The role of electricity expands across transport, buildings, cooking, and industry, supported by large-scale deployment of renewable energy, energy storage, and a strategic expansion of nuclear power to ensure system reliability. As a result, the power sector moves steadily towards near-zero emissions, while per capita electricity consumption rises to levels comparable with advanced economies. Alongside climate benefits, this transformation strengthens energy security by reducing dependence on imported fossil fuels and exposure to global price volatility.

The report highlights that while the net zero transition does not materially compromise long-term growth, it is capital-intensive and places significant demands on finance, institutions, and skills. Large upfront investments, particularly in the power sector, must be accompanied by careful management of impacts on employment, land use, and regional economies. If executed effectively, this transition can reinforce India's development objectives, strengthen resilience, and enhance long-term competitiveness in a rapidly changing global economy.

I would like to place on record my appreciation for Dr Anshu Bharadwaj, Shri Rajnath Ram, and their teams for leading this exercise, as well as the in-house modelling and drafting team comprising Venugopal Mothkoor, Anjali Jain, Nitin Bajpai, Divya Midha, Srishti Dewan, and Aastha Singh, for their analytical rigour and sustained effort.

(Suman Bery)

Place- New Delhi
Dated- 05th February, 2026

बी. वी. आर. सुब्रह्मण्यम
B.V.R. Subrahmanyam
मुख्य कार्यकारी अधिकारी
Chief Executive Officer

सत्यमेव जयते

भारत सरकार
नीति आयोग, संसद मार्ग
नई दिल्ली - 110 001
Government of India
National Institution for Transforming India
NITI Aayog, Parliament Street,
New Delhi - 110 001
Tel. : 23096576, 23096574
E-mail : ceo-niti@gov.in

FOREWORD

India stands at a defining moment in its national journey. The vision of Viksit Bharat 2047, a USD 30 trillion developed economy, demands rapid expansion of infrastructure, industry, services and opportunities for all citizens. In parallel, India has committed to achieving Net-Zero emissions by 2070. Pursuing these goals together is without historical precedent.

This report represents an integrated assessment of how India can realise this dual ambition. Under the guidance of NITI Aayog, ten inter-ministerial Working Groups examined sectoral transitions in transport, industry, buildings, agriculture, waste and power, alongside cross-cutting themes of climate finance, critical minerals, social impacts and macroeconomic implications. The modelling for this study has been undertaken by an in-house team drawing on national data and sectoral expertise. The exercise is anchored in a development-first approach, focusing not on constraining growth, but on identifying how India can grow rapidly in a sustainable manner.

The insights highlight the complexity of the transition. These are issues of energy security, energy access and energy affordability. The expansion of clean technologies will increase demand for critical minerals. Equally important are the social dimensions: land and water constraints, employment shifts, and the imperative of a just transition.

Financing will be central to success. The transition will require large investments which can only be partially met from domestic resources. The developed world will have to meet its commitments for financing the attainment of Net Zero goals.

This roadmap is conceived as a living document, to be updated periodically as technologies mature and global conditions evolve. It sets out practical actions, from efficiency and Mission LiFE to electrification, low-carbon industry, resilient cities, and stronger institutions, while placing citizens at the centre of the transition. The report is intended to serve as a strategic reference for policymakers, regulators, industry stakeholders, and investors, ensuring that India advances toward a sustainable Viksit Bharat.

I thank all the chairpersons and members of various working groups for their commitment and leadership in shaping the analysis and findings of the reports. Several knowledge partners and experts supported us during the course of this study, and I express my gratitude to all of them. Finally, I thank my NITI colleagues for undertaking this intensive exercise and completing it under the leadership of Dr. Anshu Bharadwaj and Shri Rajnath Ram and their team, Shri Venugopal Mothkoor, Dr. Anjali Jain, Shri Nitin Bajpai, Ms. Divya Midha, Shri Manoj Upadhyay, Ms. Priyanka Sarkar, Ms. Srishti Dewan and Ms. Aastha Singh, for their outstanding efforts in coordinating the work and developing a suite of models to deliver India's first comprehensive energy transition report.

5/2

[B.V.R. Subrahmanyam]

Dated: 5th February, 2026

स्वच्छ भारत
एक कदम स्वच्छता की ओर

वी अनंत नागेश्वरन
मुख्य आर्थिक सलाहकार
V. ANANTHA NAGESWARAN
Chief Economic Adviser

भारत सरकार
GOVERNMENT OF INDIA
वित्त मंत्रालय
MINISTRY OF FINANCE
आर्थिक कार्य विभाग
DEPARTMENT OF ECONOMIC AFFAIRS
कर्तव्य भवन-1, नई दिल्ली.110001
KARTAVYA BHAWAN-1, NEW DELHI-110001

Foreword

India stands at a defining juncture in its development journey. The coming decades will determine whether the nation can translate its demographic potential, entrepreneurial energy, and institutional reforms into a level of prosperity that is broad-based, resilient, and durable. The vision of *Viksit Bharat*—a developed India by the centenary of Independence in 2047—embodies this national aspiration. At the same time, India has voluntarily committed to achieving net-zero greenhouse gas emissions by 2070, signalling that its development pathway will be anchored in sustainability and responsibility. Pursuing these two objectives together is without historical precedent for an economy of India's size, scale, and stage of development.

This report, *India's Roadmap to Viksit Bharat and Net-Zero*, represents a serious and timely attempt to grapple with this dual challenge. It recognises a central reality: energy lies at the heart of India's development transformation. Rising incomes, urbanisation, industrial expansion, and improved access to services will inevitably increase energy demand. Yet the form in which this energy is produced and consumed will shape India's competitiveness, energy security, environmental quality, and long-term growth prospects. The task, therefore, is not to slow development, but to re-engineer it—to embed efficiency, electrification, and clean technologies into the very foundations of future growth.

The analysis presented here reflects an integrated assessment of how India can grow rapidly while progressively lowering its emissions intensity and, over time, absolute emissions. Through the work of multiple inter-ministerial working groups and extensive engagement with domain experts and stakeholders, the report brings together sectoral insights spanning power, industry, transport, buildings, agriculture, waste, critical minerals, finance, and the social dimensions of transition. This whole-of-economy perspective is essential, because the net-zero transition is not a single-sector exercise; it is a structural transformation of how India produces, consumes, invests, and innovates.

A key strength of the report is its explicit recognition of trade-offs and constraints. Many technologies required for deep decarbonisation are still evolving. The scale of investment required is unprecedented. Land, water, and critical minerals are emerging as binding constraints. The transition will create new jobs, but it will also disrupt existing ones, particularly in fossil-dependent regions. By confronting these realities rather than assuming them away, the report offers a credible basis for policy planning and institutional reform.

Tel.: 011-24013003, 011-24013004 | E-mail : cea@nic.in

Equally important is the report's emphasis on opportunity. India's late-developer advantage allows it to avoid locking into inefficient, carbon-intensive systems that now burden many advanced economies. With much of its future infrastructure yet to be built, India can leapfrog to cleaner, more efficient, and more resilient technologies. If executed well, the net-zero transition can strengthen energy security, reduce import dependence, improve air quality and public health, catalyse domestic manufacturing, and position India as a major supplier of clean technologies to the world. The experiences of other countries as they expand the share of renewable energy in their overall energy mix will have to be taken on board. There are still large and significant unknown unknowns and the logic of the second-mover advantage is an important one. Further, geopolitics is and will be a factor.

This document is intended as a living roadmap rather than a static blueprint. Technological costs will change, global conditions will evolve, and new evidence will emerge. Periodic updating and institutionalised review will therefore be essential. What must remain constant, however, is the strategic direction: aligning development with energy security, resilience and diversification, and growth with sustainability.

I commend the teams and stakeholders who have contributed to this extensive exercise. It is my hope that this report will serve as a foundation for informed public debate, coordinated policymaking, and sustained action—helping India demonstrate that it is possible to achieve prosperity at scale while acting as a responsible steward of the planet.

(V. Anantha Nageswaran)

Authors and Acknowledgement

Chairperson

Sh. B.V.R. Subrahmanyam
CEO, NITI Aayog

Leadership

Sh. Suman Bery
Vice Chairman, NITI Aayog

Dr. V.K. Saraswat
Member, NITI Aayog

Dr. V.K. Paul
Member, NITI Aayog

Dr. Ramesh Chand
Member, NITI Aayog

Dr. Arvind Virmani
Member, NITI Aayog

Sh. B.V.R. Subrahmanyam
CEO, NITI Aayog

Sh. V Anantha Nageswaran
Chief Economic Advisor, Govt. of India

Dr. Anil Jain
Chairperson, PNGRB

Sh. Alok Kumar
Ex-Secretary, MoP

Dr. Anshu Bharadwaj
Programme Director, Green Transition, Energy & Climate Change Division, NITI Aayog

Sh. Rajnath Ram
Adviser, Energy, NITI Aayog

Core Modelling Team

Sh. Venugopal Mothkoor
Energy and Climate Modelling Specialist, NITI Aayog

Dr. Anjali Jain
Consultant G-II, NITI Aayog

Sh. Nitin Bajpai
Consultant, NITI Aayog

Authors

Sh. Venugopal Mothkoor
Energy and Climate Modelling Specialist, NITI Aayog

Dr. Anjali Jain
Consultant G-II, NITI Aayog

Sh. Nitin Bajpai
Consultant, NITI Aayog

Ms. Divya Midha
Consultant, NITI Aayog

Ms. Srishti Dewan
Young Professional, NITI Aayog

Ms. Aastha Singh
Young Professional, NITI Aayog

Peer Reviewers

Sh. V Anantha Nageswaran
Chief Economic Advisor, Govt. of India

Smt. Chandni Raina
Advisor, Climate Change & Finance Unit, Department of Economic Affairs

Sh. Sharad Sapra
Scientist- F, MoEF&CC

Ms. Shweta Kumar
Director, MoEF&CC

Ms. Aditi Pathak
Joint Director, Climate Change & Finance Unit, DEA

Sh. Ajay Raghav
Scientist- E, MoEF&CC

Ms. Ritika Bansal
Deputy Director, Climate Change & Finance Unit, DEA

Technical Editors

Smt. Rishu Nigam
Communication Specialist (Independent)

Working Group Members

Secretary, Department of Economic Affairs, Ministry of Finance

Secretary, Ministry of New and Renewable Energy

Secretary, Ministry of Petroleum and Natural Gas

Secretary, Ministry of Power

Secretary, Ministry of Coal

Secretary, Ministry of Heavy Industries

Secretary, Ministry of Steel

Secretary, Ministry of Mines

Secretary, Ministry of Micro, Small and Medium Enterprises

Secretary, Ministry of Environment, Forest and Climate Change

Secretary, Ministry of Skill Development and Entrepreneurship

Secretary, Department for Promotion of Industry and Internal Trade, Ministry of Commerce and Industry

Secretary, Ministry of Housing and Urban Affairs

Secretary, Ministry of Agriculture and Farmers Welfare

Chief Economic Advisor, Ministry of Finance

Communication and Research & Networking Division, NITI Aayog

Ms. Anna Roy
Programme Director, Research & Networking

Sh. Yugal Kishore Joshi
Lead, Communication

Ms. Keerti Tiwari
Director, Communication

Dr. Banusri Velpandian
Senior Specialist, Research and Networking

Ms. Sonia Sachdeva Sharma
Consultant, Communication

Sh. Sanchit Jindal
Assistant Section Officer, Research and Networking

Sh. Souvik Chongder
Young Professional, Communication

NITI Design Team

NITI Maps & Charts Team

Contents

List of Figures

List of Tables

List of Abbreviations

AC	Air Conditioning
ADEETIE	Assistance in Deploying Energy Efficient Technologies in Industries and Establishments
AEL	Alkaline Electrolyser
AMBER	Accelerated Mission for Better Employment and Retention
AIPA	Committee for Implementation of the Paris Agreement
ASSET	Accelerating Sustainable State Energy Transition
ATF	Aviation Turbine Fuel
AVISTEP	Avian Sensitivity Tool for Energy Planning
AWD	Alternate Wetting and Drying
BCSS	Battery Charging cum Swapping Stations
BEE	Bureau of Energy Efficiency
BEMS	Building Energy Management Systems
BESS	Battery Energy Storage Systems
BIS	Bureau of Indian Standards
BMSCM	Billion Standard Cubic Meters
BPKM	Billion Passenger-Kilometres
BPKP	Bharatiya Prakritik Krishi Paddhati
BRSR	Business Responsibility and Sustainability Reporting
BS	Bharat Stage (emission standards)
BTKM	Billion Tonne-Kilometres
BTR	Biennial Transparency Report
BUR	Biennial Update Report
CAD	Current Account Deficit
CBAM	Carbon Border Adjustment Mechanism
CBDR	Common But Differentiated Responsibilities
CBG	Compressed Biogas
CCS	Carbon Capture and Storage
CCTS	Carbon Credit Trading Scheme
CCUS	Carbon Capture, Utilisation, and Storage
CDRI	Coalition for Disaster Resilient Infrastructure
CEA	Central Electricity Authority

CEEW	Council on Energy, Environment and Water
CETM	Critical Energy Transition Minerals
CGE	Computable General Equilibrium
CH_4	Methane
CLEW	Climate-Land-Energy-Water
COPD	Chronic Obstructive Pulmonary Disease
CPS	Current Policy Scenario
CRIRSCO	Committee for Mineral Reserves International Reporting Standards
CRM	Critical Raw Materials
CSP	Concentrated Solar Power
CSS	Centrally Sponsored Scheme
Co-WIN	Covid Vaccine Intelligent Network
DAC	Direct Air Capture
DEA	Department of Economic Affairs
DISCOM	Distribution Company
DLE	Direct Lithium Extraction
DMF	District Mineral Foundation
DPI	Digital Public Infrastructure
DRE	Decentralised Renewable Energy
DRI	Direct Reduced Iron
DSR	Direct-Seeded Rice
ECBC	Energy Conservation Building Code
ECSBC	Energy Conservation and Sustainable Building Code
EJ	Exajoule
ELV	End-of-Life Vehicle
ENS	Eco-Niwas Samhita
EPC	Engineering, Procurement, and Construction
EPI	Energy Performance Index
EPR	Extended Producer Responsibility
ERC	Evacuation-Ready Certificate
EUDR	EU Deforestation Regulation
FAR	Floor Area Ratio
FDRE	Firm Dispatchable Renewable Energy
FOAK	First-of-a-Kind
FOD	First Order Decay
FPI	Foreign Portfolio Investment
FSDC	Financial Stability and Development Council
GCA	Gross Cropped Area
GER	Gross Enrolment Ratio
GH_2	Green Hydrogen
GHG	Greenhouse Gas
GIFT	Gujarat International Finance Tec-City

GJ	Gigajoule
GPP	Green Public Procurement
GST	Goods and Services Tax
GVA	Gross Value Added
GWP	Global Warming Potential
HCI	Human Capital Index
HDI	Human Development Index
HIC	High-Income Countries
HS	Harmonised System (commodity codes)
IBAT	Integrated Biodiversity Assessment Tool
IBC	Insolvency and Bankruptcy Code
ICAP	India Cooling Action Plan
ICED	India Climate and Energy Dashboard
ICLEI	Local Governments for Sustainability
IDSP	Integrated Disease Surveillance Programme
IEA	International Energy Agency
IFSCA	International Financial Services Centres Authority
ILO	International Labour Organization
IMR	Infant Mortality Rate
IPHS	Indian Public Health Standards
IPPU	Industrial Processes and Product Use
ISA	International Solar Alliance
KABIL	Khanij Bidesh India Limited
LC3	Limestone Calcined Clay Cement
LCA	Life Cycle Assessment
LCDC	Low Carbon Development Commission
LEN	Livelihoods, Environment, Nutrition
LGTM	Long-Term Growth Model (duplicate of LTGM)
LTGM	Long-Term Growth Model
MANAGE	Macroeconomic Net Zero Analysis & Growth Evaluation (economic model)
MBBL	Model Building Bye-Laws
MEPS	Minimum Energy Performance Standards
MoEFCC	Ministry of Environment, Forest and Climate Change
MoHUA	Ministry of Housing and Urban Affairs
MoPNG	Ministry of Petroleum and Natural Gas
MRV	Monitoring, Reporting and Verification
MSP	Minerals Security Partnership
MSW	Municipal Solid Waste
NAPCC	National Action Plan on Climate Change
NBC	National Building Code
NCAER	National Council of Applied Economic Research

NCAP	National Clean Air Programme
NDC	Nationally Determined Contribution
NEP	National Education Policy
NFSA	National Food Security Act
NGFI	National Green Finance Institution
NHM	National Health Mission
NIP	National Infrastructure Pipeline
NMEEE	National Mission for Enhanced Energy Efficiency
NMET	National Mineral Exploration Trust
NMM	National Manufacturing Mission
NMNF	National Mission on Natural Farming
NMP	National Monetisation Pipeline
NMT	Non-Motorised Transport
NPCCHH	National Programme on Climate Change and Human Health
NUE	Nitrogen Use Efficiency
NZS	Net Zero Scenario
N_2O	Nitrous Oxide
OOPE	Out-of-Pocket Expenditure
ORDENA	(CEA's power capacity expansion model)
OSHWC	Occupational Safety, Health and Working Conditions (Code)
PAT	Perform, Achieve and Trade
PDS	Public Distribution System
PESA	Panchayats (Extension to the Scheduled Areas) Act
PFC	Perfluorocarbon
PKM	Passenger Kilometre
PKVY	Paramparagat Krishi Vikas Yojana
PLI	Production-Linked Incentive
PMCCC	Prime Minister's Council on Climate Change
PMDDKY	Pradhan Mantri DhanDhaanya Krishi Yojana
PMKVY	Pradhan Mantri Kaushal Vikas Yojana
PMUY	Pradhan Mantri Ujjwala Yojana
PNG	Piped Natural Gas
PUE	Power Usage Effectiveness
PV	Photovoltaic
RAC	Room Air Conditioner
RE	Renewable Energy
REE	Rare Earth Elements
RFCTLARR	Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement Act
RKVY	Rashtriya Krishi Vikas Yojana
RRTS	Regional Rapid Transit System
SAF	Sustainable Aviation Fuel

SAPCC	State Action Plan on Climate Change
SAPCCHH	State Action Plan on Climate Change and Human Health
SATAT	Sustainable Alternative Towards Affordable Transportation
SEC	Specific Energy Consumption
SHANTI	Sustainable Harnessing of Nuclear Energy for Transforming India Act
SIPS	System Integrity Protection Schemes
SLR	Statutory Liquidity Ratio
SRI	System of Rice Intensification
STEM	Science, Technology, Engineering and Mathematics
TAF	Technology Assessment Framework
TB	Tuberculosis
TCO	Total Cost of Ownership
TEE	Technical, Economic and Environmental
TFP	Total Factor Productivity
TKM	Tonne Kilometre
TOD	Transit-Oriented Development
TPES	Total Primary Energy Supply
UEI	Unified Energy Interface
ULB	Urban Local Body
UMIC	Upper Middle-Income Countries
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UPI	Unified Payments Interface
UJALA	Unnat Jyoti by Affordable LEDs for All
VRE	Variable Renewable Energy
WACC	Weighted Average Cost of Capital
ZEV	Zero-Emission Vehicle
CPCB	Central Pollution Control Board
SPCB	State Pollution Control Board
ONDC	Open Network for Digital Commerce
OCEN	Open Credit Enablement Network

Executive Summary

India is at the cusp of an unprecedented opportunity in its economic history. It is benefitting from a youthful population with a median age of 28 giving a demographic dividend which will last for the next quarter century. At the same time, its growth is being boosted by the strong momentum of fast rising economic indicators such as savings, investments, and expectations. In this context, the Hon'ble Prime Minister has set an ambitious goal of making India Viksit Bharat, a developed nation by 2047.

This developmental journey has no historical precedent. The comprehensive development agenda under Viksit Bharat, which envisions increasing GDP to USD 30 trillion by 2047 involves building the infrastructure, services, and opportunities needed for a better quality of life for all. At the same time, India has committed to achieving Net Zero greenhouse gas emissions by 2070. Pursuing these goals together represents an unprecedented experiment: no major economy has attempted to scale its GDP nearly eightfold within a single generation while simultaneously redirecting its energy system, industrial structure, and resource use toward a low-carbon pathway. The central challenge is to achieve both objectives in a balanced manner. This is further complicated by the fact that many of the technologies needed for Net Zero, such as carbon capture, utilisation and storage (CCUS), long-duration energy storage, and small modular nuclear reactors, remain nascent, and unproven at scale. The aspiration to become a developed nation is unfolding at a time when climate change impacts are becoming increasingly ubiquitous, with the burden felt most acutely by marginalised communities. Adaptation is therefore critical and, as the Economic Survey 2025–26 notes, "development is, in itself, a form of adaptation"

In this context, in order to facilitate coordinated policymaking and planning, NITI Aayog constituted ten Inter-Ministerial Working Groups to develop an integrated assessment of how India can achieve the vision of Viksit Bharat 2047 while simultaneously reducing the net greenhouse gas (GHG) emissions to zero by 2070. These working groups examined various facets of the transition spanning sectoral aspects in transport, industry, buildings, agriculture, waste, and power, as well as cross-cutting themes of critical minerals, climate finance, social aspects and macroeconomic implications. Each working group brought together policymakers, domain experts and industry stakeholders and validated multiple inputs and outputs of this endeavour.

India's low-emission development strategies continue to be guided by the foundational principles of the United Nations Framework Convention on Climate Change (UNFCCC) – equity, climate justice and the principle of common but differentiated responsibilities and respective capabilities. This overarching framework for India's Net Zero transition, as reiterated in the Long-term Low Emission Development Strategy (LT-LEDS) submitted by India to the UNFCCC in November 2022, forms the basis of this report.

NITI Aayog's *A Study Report on Scenarios Towards Viksit Bharat and Net Zero: An Overview* is an independent analytical exercise based on modelled scenarios that are indicative, not predictive or prescriptive. Results rely on assumptions and are subject to uncertainties, including future policy choices, technology evolution, finance availability, and global economic and geopolitical conditions. Accordingly, the report should be read as an input for research and policy dialogue, and not as an official policy position or a definitive pathway.

The consolidated report integrates the findings from these working groups into a coherent national roadmap. It is designed as a living document to be updated every few years as technologies advance, cost curves change and global dynamics evolve. This is to ensure that India's pathways remain relevant, responsive and anchored in the realities of technological and economic transformation.

A central component of this effort is the modelling framework, which integrates multiple sectoral models into a unified system linking India's developmental goals and Net Zero pathways. Two scenarios inform the analysis.

i. **Current Policy Scenario (CPS)**: The Current Policy Scenario represents a level of effort that is realistically achievable based on historical trends and continuation of current policies (as of 2023), thereby projecting ongoing trends in low-carbon technology deployment.

ii. **Net Zero scenario (NZS):** The Net Zero Scenario reflects an ambitious pathway aligned with India's commitment to achieve Net Zero GHG emissions by 2070. It incorporates both existing and additional policy measures to accelerate demand electrification, enhance circularity, improve energy efficiency, promote the rapid development of low-carbon technologies/fuels and encourage behavioural shifts.

Viksit Bharat 2047: India's Development Foundation for a Net Zero Future

The Hon'ble Prime Minister's Viksit Bharat vision is anchored in a significant expansion of the economy. GDP is expected to rise from USD 4.18 trillion (2025) to USD 30 trillion (2047), accompanied by a sustained acceleration in industrial output, services growth, and infrastructure investment. India's urban population is expected to rise from 37% in 2023 to 51% by 2047 and 65% by 2070, implying substantial expansion of existing cities and the emergence of new urban centres. Rising incomes and urbanisation will increase per-capita energy demand through higher mobility requirements, widespread appliance use, cooling needs, and the growth of commercial services (Table E1 below). At the same time, it creates opportunities for compact design, mass transit, and efficient buildings that reduce long-term energy intensity.

Table E1: Select Indicators of Development

	2023	2047	2070
Urbanisation	37%	51%	65%
Buildings Floor Space (Billion m^2)	18	37	42
Number of Cars (per 1,000 people)	32	130-170	200-250
AC Penetration	10%	65%	80%

Transport – Passenger (BPKMS)	5,693	16,450-18,000	19,400-22,600
Transport – Freight (BTKM)	4,143	10,000-12,700	13,000-16,200
Industrial Production – Steel (Mt)	127	568	821
Industrial Production – Cement (Mt)	391	1,471	1,985
Farm Mechanisation	47%	100%	100%

The sectoral development choices for meeting the surge in demand involve trade-offs. For example, a greater thrust towards the use of Transit-Oriented Development (TOD) principles in urban planning will lead to reduced overall travel demand. Similarly, the emphasis on reuse and recycling will result in lower demand for virgin industrial inputs. These developmental choices, embedded in the sectoral transition plans, are not constraints on growth but enablers of sustainable prosperity.

Pathways to Net Zero: Energy Mix and Emissions

Energy Demand: India's final energy demand is projected to increase from 688 Mtoe (2025) to 1381-1617 Mtoe by 2050 and 1465-1811 Mtoe by 2070. This moderate increase of 2.1-2.6 times by 2070 over 2025 levels, not withstanding an 11-fold increase in GDP, is driven by reduced energy intensity. Final energy demand in the Net Zero Scenario at 1465 Mtoe is 20% lower than Current Policy Scenario energy demand of 1811 Mtoe in 2070, driven by higher electrification, circularity, energy efficiency, and saturation of sectoral activity. This decoupling of energy-GDP is consistent with global experience.

Industrial share in the final energy demand is projected to increase from 54% in 2025 to 60-64% by 2050 and 63-67% by 2070, as the demand for commodities such as steel, cement, aluminium, etc., increases with rising per-capita income as India converges toward global per-capita consumption norms. Beyond 2050, India enters a post-infrastructure phase of development. Per-capita demand for industrial commodities and transport begins to saturate. Growth beyond 2050 shifts from infrastructure build-out to services, digital infrastructure, and lifestyle diversification.

Primary Energy Mix: India's primary energy supply increase by 2.0-2.3 times by 2050 and 2.1-2.5 times by 2070 over 2025 levels, reflecting the decoupling of energy and GDP, i.e. Energy Intensity to GDP falls from 0.22 MJ/INR in 2025 to 0.09-0.1 MJ/INR by 2050 and 0.04-0.05 MJ/INR by 2070. Also, India will be able to achieve high Human Development Index (HDI) levels of 0.8 and above with 55-60 GJ per-capita consumption, while other developed economies report per-capita consumption at 100 GJ and above. However, there are important changes in the energy mix. The primary energy mix changes from fossil-fuel dominant at 87% in 2025 to a reduced use, even in the Current Policy Scenario, where fossil fuels account for 54% by 2070. In the Net Zero Scenario, their share is projected to reduce to 14%, and this remaining fossil capacity that exists largely leverages carbon capture solutions to mitigate emissions.

Table E2: Summary of Energy Indicators

Indicator	2025	Current Policy Scenario		Net Zero Scenario	
		2050	2070	2050	2070
Final Energy Demand (Mtoe)	688	1620	1810	1380	1465
Primary Energy Supply (Mtoe)	1006	2286	2492	2058	2159
Demand Electrification	21%	32%	40%	42%	60%
Per-capita Primary Energy (GJ/capita)	30	60	64	54	56

Demand Electrification: Electricity's share of final energy is projected to rise from about 21% in 2025 to 40% in Current Policy Scenario and 60% in Net Zero Scenario by 2070. This is on account of higher EV penetration in transport, greater use of electricity-based heat in industry through the adoption of heat pumps, electric boilers, etc. and increased use of electricity in cooking. Renewables form the backbone of this transition, projected to rise from 3% share in 2025 to 63% by 2070 under the Net Zero Scenario, driven by sustained decline in technology costs and enhanced role of storage.

Bioenergy transitions from traditional household use to modern applications in fuels and industry, while natural gas acts as a bridge fuel, with its infrastructure capable of being repurposed to support Compressed Bio-Gas (CBG) and Green Hydrogen (GH_2).

India's transformation of its energy mix is not only critical for achieving Net Zero emissions but also delivers significant economic and geopolitical benefits. Reduced dependence on imported oil (89% in 2024) and gas (47% in 2024), along with lower exposure to fossil fuel price volatility, strengthens the country's energy security and enhances its long-term strategic autonomy.

Electricity*:* With the greater emphasis on use of electricity across various sectors – industry, transport, cooking etc., electricity demand is projected to increase by 4-5 times by 2050 and 6-8 times by 2070 over 2025 levels. India's per-capita electricity consumption is projected to increase from 1400 kWh in 2025 to 7,000 kWh-10,000 kWh by 2070, reflecting levels seen in advanced economies such as France, and South Korea.

India's power system undergoes a decisive shift towards clean power. Variable Renewable Energy (VRE) capacity, Solar and Wind, is expected to increase from 164 GW in 2025 to over 3000 GW in 2050 and over 6000 GW in 2070 in Net Zero Scenario as compared to ~2000 GW (2050) and over 4000 GW (2070) in Current Policy Scenario. These large-scale capacity additions in VRE in both scenarios are primarily driven by commercial considerations and the enhanced role of storage. Further, nuclear energy emerges as a strategic pillar, scaling up from ~8 GW in 2025 to over 300 GW by 2070, providing firm, low-carbon power and enhancing system reliability.

Table E3: Power Sector Summary of Results

Indicator	2024	Current Policy Scenario		Net Zero Scenario	
		2050	2070	2050	2070
Electricity Consumption (TWh)	1541	6500	9800	8100	13000

Per-Capita Electricity (kWh/ capita)	1400	4600-4800	6900-7400	5100-5200	9900-9910
Non-Fossil Electricity in Generation (%)	23%	66%	91%	78%	0%
Nuclear Capacity (GW)	8	50-60	90-130	95-105	290-320
Renewables Capacity (GW)	136	1890-2200	4150-4200	3150-3200	6150-6700
Grid Emission Factor (kgCO_2/kWh)	0.72	0.3	0.23	0.07	0

Non-fossil fuel power generation (including captive) share is expected to increase from 23% in 2025 to 65% in Current Policy Scenario and 80% in Net Zero Scenario by 2050. It is further expected to rise above 80% by 2070 in Current Policy Scenario, and to 100% in the Net Zero Scenario. As a result of these systemic shifts, the grid emission factor declines from 0.72 kgCO_2/kWh in 2025 to 0-0.23 kgCO_2/kWh by 2070.

Emissions Trajectory: India's GHG emissions grow from a low base of 2.6 GtCO_2 in 2019 as the country embarks on a mission to become a developed economy by 2047. However, with declining energy intensity to GDP from 0.22 MJ/INR in 2025 to 0.09 MJ/INR by 2050 and 0.04 MJ/INR by 2070 in the Net Zero Scenario, the impact on emissions is not proportional. The projected decline is driven by improvements in energy efficiency, demand electrification and technology switch to low-carbon fuels.

However, even with low carbon initiatives across sectors, residual emissions remain in 2070, particularly in agriculture, industrial process emissions, and niche fossil fuel use such as aviation. These residual emissions may be addressed through the deployment of carbon capture solutions, including sink.

Enabling the Net Zero Transition

India's vision of becoming a developed economy by 2047 and achieving Net Zero emissions by 2070 requires a delicate balancing act. Many of the technologies needed for Net Zero have yet to reach commercial maturity, while mature low-carbon technologies often demand large up-front investments. Moreover, the transition exposes the economy to new vulnerabilities in the form of critical mineral dependencies, land requirements for deploying renewables, and an employment shift requiring large-scale skilling and reskilling of labour in emerging clean industries. The huge scale of finance needed for this transition needs to be mobilised and the implications for the country's macroeconomic stability also need examination.

Financing the Transition: Scale, Gaps, and Capital Structure

The study estimates cumulative investment requirements of USD 22.7 trillion by 2070 under the Net Zero Scenario, with the power sector accounting for over half of total needs, reflecting its central role in enabling economy-wide electrification and the expansion of low-carbon generation. On an annualised basis, this cumulative requirement translates into average flows of approximately USD 500 billion per year, compared with actual annual investment of around USD 135 billion in 2024, of which only USD 70–80 billion currently supports clean energy.

Of this total, approximately USD 8 trillion must be front-loaded by 2050, including nearly USD 5 trillion in the power sector, given the capital-intensive nature of most low-carbon technologies. While absolute investment estimates vary across studies due to differences in scope, methodology and time horizon, the sectoral pattern is consistent: the power sector dominates, followed by transport and industry.

Comparative estimates place total investment requirements at USD 14.7 trillion under the Current Policy Scenario and USD 22.7 trillion under Net Zero Scenario, implying an incremental requirement of USD 8.1 trillion to align with Net Zero pathways. This incremental investment reflects the cost of accelerated low-carbon deployment, supporting policies and system-level interventions.

With coordinated domestic and external reforms, India could credibly mobilise around USD 16.2 trillion towards its Net Zero transition by 2070 through a structural expansion in the scale, depth and efficiency of available capital. Domestically, this entails deepening the corporate bond market, increasing the financialisation of household savings, and enabling institutional investors to invest in new areas, while safeguarding returns through diversified, high-quality corporate and green assets. Externally, scaling FDI and FPI, supported by credible transition roadmaps, a strong pipeline of bankable projects and deeper financial markets, would anchor sustained foreign capital inflows.

Against the Net Zero Scenario investment requirement of USD 22.7 trillion and estimated aggregate flows of USD 16.2 trillion, a financing gap of USD 6.53 trillion remains. Given domestic constraints and the risk of crowding out and higher interest rates, this gap is expected to be met largely through external sources, raising the share of international sources to 42% of total capital needs by 2070, rising from 17% in 2022–23. International capital, particularly concessional finance and grants, will therefore be critical to supporting technologies essential for Net Zero that are not yet commercially viable.

Macroeconomic Implications of India's Net Zero Transition

The Net Zero transition has limited impact on long-term GDP growth but demands high investment. India's GDP is projected to stay broadly resilient even in Net Zero scenarios, reaching USD 30 trillion by 2047 which is aligned to the Viksit Bharat goal. While the transition demands massive capital mobilisation, scenarios with higher share of foreign financing limit total GDP variations to about 0.5% by 2050. This highlights the importance of the financing structure: mobilising external capital, such as FDI, prevents pressure on domestic savings and avoids crowding out private investment.

Growth Structure Shifts from Consumption-Led to Investment-Driven: Private consumption's share in GDP is projected to be lower, going from 58% in 2025 to 52% in 2070, while investment share is projected to rise from 32% in 2025 to around 36% by 2050 before moderating to 34% by 2070, a trend seen in other developed economies. Domestic financing tightens liquidity and crowds out consumption, whereas foreign financing sustains both investment and demand, signalling a long-term structural rebalancing towards capital-intensive growth.

Trade Becomes More Resilient with Lower Fossil Fuel Dependence: Imports and exports are projected to grow in absolute terms as India moves to high-income status, and remain broadly stable at 23–25% of GDP by mid-century in the Current Policy Scenario. Differences across Net Zero pathways are driven largely by financing choices. Domestically financed scenarios show reduction in potential exports, reflecting higher domestic costs and tighter resource constraints, but these are offset by substantial projected reductions in fossil fuel imports, resulting in lower overall trade exposure. Scenarios with higher share of foreign financing have far less variations in exports by supporting higher investment, though they are associated with larger current account and trade deficits in the medium term due to higher capital inflows. The current account deficit is projected to widen slightly in the near term, peaking at around 3.0–3.2% of GDP in the mid-2040s, before improving to about 2.3–2.5% by 2070, signalling a gradual strengthening of the external balance.

Industry expands, driven by clean energy: The Net Zero transition accelerates structural change, boosting the projected industry GDP share to 33% by mid-century and stabilising thereafter, driven by clean energy and manufacturing. Manufacturing remains central as India scales domestic clean-tech capacity.

Fossil-Fuel Revenue Losses Offset by Import Savings and Green Transition: In the Net Zero Scenario, fossil-fuel revenues are projected to reduce from 2.3% of GDP in 2022 to 0.5% by 2050 and 0.2% by 2070, while the fuel import bill is expected to drop from 4% of GDP in 2022 to 0.9% by 2050 and 0.2% by 2070. Although critical mineral imports are projected to rise, total import savings is expected to be INR 9 trillion by 2070 (in 2011-12 prices), strengthening fiscal and external resilience.

Critical Minerals and Supply Chain Security

The demand for Critical Energy Transition Minerals (CETMs) is estimated based on the anticipated scale and composition of low-emission technology deployment. It covers a defined set of technologies central to India's energy transition, including solar PV and concentrated solar power, wind turbines, electric vehicles (EVs), battery energy storage systems (BESS), and hydrogen electrolysers.

Under the Net Zero Scenario, cumulative CETM demand is projected to rise sharply from around 3.5 Mt during 2025–30 to nearly 54 Mt over 2030–50, and above 110 Mt during 2050–70. The sharp post-2050 increase reflects the accelerated rollout of renewable capacity alongside the rapid expansion of green hydrogen and energy storage systems. Overall CETM demand through 2070 in the Net Zero Scenario is projected to be around 51% higher than in the Current Policy Scenario, underscoring the material intensity of an ambitious Net Zero pathway.

EV batteries are projected to dominate total CETM demand, accounting for roughly 55%, followed by solar technologies at about 30%. Copper and graphite emerge as the most critical minerals, together comprising nearly two-thirds of cumulative demand by 2070. Copper demand is driven primarily by solar (around 50%) and EV batteries (about 30%), while graphite demand is overwhelmingly concentrated in EV batteries (over 90%). Silicon demand rises to approximately 19 Mt, largely for solar applications.

Although rare earth elements such as neodymium and dysprosium represent a smaller share of total volumes, they remain strategically critical due to their essential role in EV motors and permanent magnets. This surge in demand poses material risks to domestic energy security, particularly given the high concentration of global supply chains.

While copper and graphite benefit from notable domestic resources with moderate import dependence, India remains almost fully reliant on imported polysilicon despite low overall silicon import dependence, pointing to gaps in processing and refining capacity rather than geological scarcity. In contrast, minerals such as lithium, nickel, cobalt and rare earth elements face near-total import dependence due to the absence of domestic reserves. This supply-demand profile highlights the urgency of strengthening India's CETM ecosystem through enhanced exploration, faster reserve certification, expansion of domestic processing infrastructure, diversified international sourcing partnerships, and the scaling of circular economy pathways.

Circularity assessments indicate that by mid-century, 20–25% of copper and graphite demand could be met through recycling, while silicon remains below 10% due to technical barriers. In comparison, cobalt (approaching 100% circularity by 2040–45) and nickel (up to 45%) exhibit significantly higher recycling potential, reinforcing that economic value and recoverability are critical drivers of circularity in CETMs.

Social, Spatial, and Behavioural Dimensions of the Transition

India's energy transition is a socio-economic transformation as much as a technological one, with deep implications for land, water, livelihoods, and equity. Achieving the goals of becoming a developed economy by 2047 and Net Zero by 2070 requires balancing mitigation with adaptation and resilience under acute resource constraints. Although aggregate land requirements for the power sector under Net Zero appear modest relative to estimated wastelands (about 11%), this requirement masks intense competition over land for agriculture, housing, industry, and ecosystems, especially in densely populated and ecologically fragile regions.

Renewable expansion is intensifying these pressures unevenly. Balance has to be struck between productive agricultural land, ecologically sensitive areas, and "wastelands" while meeting the land needs of solar and wind projects. These impacts are spatially concentrated: nearly 75% of renewable capacity is clustered in a few water-stressed states creating distributional risks.

Labour impacts further underscore the need for an inclusive transition. While the Net Zero pathway is projected to generate more employment than the Current Policy Scenario, with energy-sector jobs projected to rise by about 7 million by 2050 (1 million additional jobs vs Current Policy Scenario) and driving large gains in construction, transport, and trade, these benefits are not spatially neutral. Fossil-fuel linked manufacturing employs nearly 17 million workers and faces gradual but profound restructuring pressures, with over 150 districts dependent on coal, thermal power and fossil assets. Targeted reskilling, social protection, and regional diversification are critical to ensure that the transition has balanced equitable outcomes, even as India's low-consumption lifestyles and initiatives like Mission LiFE offer a strategic advantage for aligning low-carbon growth with equity and public health co-benefits.

Behavioural change and resource efficiency are essential complements to technological solutions. Initiatives like Mission LiFE, the Long-Term Low-Emissions Development Strategy (LT-LEDS), and the National Action Plan on Climate Change (NAPCC) recognise the role of individual and community behaviour in influencing energy demand and material consumption. Addressing resource-intensive behaviours such as high-emission mobility patterns, inefficient cooling practices, and food waste systematically can help moderate future demand and reduce dependence on virgin resources. These measures also support energy security and reduce pressure on land and water.

Way Forward to India's Net Zero Transition

Realising India's aspirations of becoming Viksit Bharat i.e., a developed economy by 2047 and achieving the Net Zero goal by 2070 will require an enabling ecosystem that spans robust institutions, innovative finance, integrated data systems, and strategic planning. By strengthening these foundational elements, sectoral transitions scale rapidly, affordably, and equitably. Based on cross-sectoral evidence, the following high-level actions are critical.

1. Anchor the transition in demand moderation, efficiency, and circularity

Demand-side action is the most cost-effective lever available to India and should be accorded equal priority to the expansion of clean energy supply. An economy-wide Avoid–Shift–Improve approach may guide policy across transport, buildings, and industry. This entails adoption of super-efficient appliances and equipment, scaling up of industrial retrofits (especially among MSMEs), acceleration of circular material flows through recycled-content standards and extended producer responsibility, and systematic integration of behavioural change initiatives such as Mission LiFE. Effective management of demand growth will reduce infrastructure requirements, lower import dependence, alleviate pressure on land and mineral resources, and enhance affordability, thereby enabling the transition faster and more resilient.

2. Promote demand electrification alongside power sector transition to cleaner sources

Electrification across mobility, buildings, cooking, and industrial heat must become the principal pathway for low-carbon growth. This transformation can be achieved by concurrently rebuilding power system to deliver scale, flexibility, and reliability. Key priorities include accelerating the deployment of renewable energy with storage and hybrid configurations, scaling nuclear power as a source of clean baseload power, modernising and enhancing the flexibility of the coal fleet during the transition, and strengthening transmission and distribution networks. The nationwide implementation of time-of-day tariffs, dynamic pricing, ancillary service markets, and digital grid management is essential to align demand with the availability of renewable energy. These reforms will ensure electrification, reduce costs, and increase reliability.

3. Reorient urban and mobility systems toward public and shared transport

With passenger and freight movement expected to rise manifold, the structure of urban form and modal choice will be the primary determinants of transport outcomes, rather than vehicle technology alone. Policy direction ought to emphasise the development and integration of rail, metro, buses, non-motorised transport, and waterways, supported by transit-oriented development planning, parking reform, and congestion management. Advancing zero-emission vehicle mandates, EV-ready building codes, interoperable charging infrastructure, and fleet electrification can proceed in parallel with large-scale investment in mass transit and freight corridors. Facilitating the shift of people and goods to more efficient modes will yield emissions reductions, alleviate congestion, improve air quality, and reduce dependence on oil.

4. Lock in efficient buildings before the construction boom peaks

With more than 80% of future floor space yet to be built, the building sector presents a singular opportunity to avoid inefficient energy use. Energy and building codes need to evolve from design-stage intent to performance-based outcomes that are consistently enforced. This requires embedding codes into municipal bylaws, digitising approvals and compliance processes, professionalising third-party assessment, and expanding standards to cover residential buildings and retrofits. Progressive inclusion of thermal performance, whole-life and embodied carbon, commissioning, and climate resilience will be critical. Market-based instruments such as benchmarking, disclosure, appliance standards, green procurement, and workforce skilling can reinforce these measures, making Net Zero ready buildings the norm rather than the exception.

5. *Enable transition in industry without compromising competitiveness*

The industrial sector is poised for expansion to support both development and the energy transition, positioning clean industrial growth as a strategic imperative. Near-term gains lie in energy efficiency, electrification, and circularity, particularly among MSMEs, while frontier technologies are piloted and scaled. Targeted support can de-risk green hydrogen, CCUS, low-carbon cement, and advanced materials through demonstration funding, blended finance, assured offtake, and public procurement. At the same time, India must prepare for emerging trade regimes by strengthening carbon measurement, certification, and product standards. Competitiveness in a carbon-constrained global economy will hinge on early and decisive action.

6. *Build a resilient domestic supply chain for clean technologies and critical materials*

The Net Zero transition will sharply increase demand for critical minerals, components, and advanced manufacturing. Avoiding substitution of fossil-fuel dependence with new forms of import dependence requires accelerated domestic exploration and credible geological data, alongside production-linked incentives that strengthen downstream manufacturing. Midstream resilience depends on scaling refining, and advanced recycling capacity through coordinated incentives, technology access, and reliable secondary feedstock, while maintaining environmental and social safeguards. International exposure can be reduced by diversifying overseas mineral access through risk-differentiated partnerships, embedding India in resilient global value-chain arrangements, and strengthening institutions such as KABIL for overseas execution. Trade policy, standards, skills development, and mission-oriented R&D frameworks aligned with pilot-to-commercial pathways will build domestic innovation and technology capability

7. *Plan land and water use proactively*

Land and water are emerging as critical for clean energy deployment. Integrated spatial planning is required to reconcile renewable energy, transmission, urban growth, agriculture, and ecosystem protection needs. Priority measures include advancing land-neutral options such as agrivoltaics and floating solar, repurposing degraded and mined areas, and adopting basin-aware water strategies for hydrogen and cooling.

8. *Anchor people, jobs, and affordability in the transition*

India's Net Zero transition will impact employment in a differentiated manner across regions, requiring a national framework for retraining, relocation, and diversification. District Mineral Foundations, the Skill India Mission, and the Skill Council for Green Jobs can finance worker shifts into green sectors, supported by integrated district-level plans that combine diversification, infrastructure, and workforce support. Strengthening labour data through an upgraded e-Shram platform will link informal occupations to fossil-linked industries, while expanded access to ESIC, health insurance, and pensions protects those facing displacement. Local transition units can coordinate benefits and outreach to women and marginalised groups, and sector-specific skill roadmaps aligned with state low-carbon growth pathways will guide reskilling into low-carbon roles across renewables, grid modernisation, electric mobility, energy efficiency, and climate-resilient sectors.

9. Treat adaptation and resilience as integral to Net Zero delivery

Managing the transition requires giving importance to mitigation. Mitigation needs complementing with systematic investment in resilience, through vulnerability mapping, adaptation costing, climate-proofing of infrastructure, and strengthened health, water, and disaster-risk systems. Early investment in resilience reduces long-term fiscal burdens and protects development gains, ensuring that Net Zero pathways remain viable under worsening climate risks.

10. Mobilise finance at scale through dedicated institutions and market reform

India's Net Zero transition will require around USD 500 billion per annum, far above current annual flows that stand at only one-quarter to one-fifth of this level. The challenge lies less in capital availability than in intermediation, risk management, and cost of capital. A National Green Finance Institution can anchor blended finance, guarantees, project preparation to crowd in private and foreign capital, including sovereign wealth funds. A unified climate finance taxonomy will strengthen disclosures, prudential treatment, and market confidence. Deepening corporate bond markets, expanding IFSC/GIFT co-investment platforms, development of bankable project pipeline and deploying transition-finance instruments will be critical to funding both greenfield and brown-to-green investments without constraining growth.

11. Mission-Mode Implementation and Innovation accelerates change

Past national missions in sanitation, digital payments, social security, and infrastructure demonstrate India's capacity to deliver when institutions, targets, and funding are aligned. The Net Zero transition requires mission-mode programmes that concentrate effort, funding, and innovation on cross-sector priorities. Strategic missions on demand-side management, circular economy, systemic electrification, and industrial innovation emerge as priority areas.

12. Establish robust data, digital rails, and Monitoring, Reporting & Verification (MRV) systems as core infrastructure

Credible, interoperable data underpins planning, markets, and trust. Harmonisation of energy and emissions statistics, development of state-level inventories aligned with national reporting, and upgraded digital platforms for real-time monitoring and settlement are essential. The Unified Energy Interface provides a foundation for interoperable EV charging and energy services, while integrated dashboards can reduce transaction costs, enable demand response, and strengthen accountability. Data and digital systems constitute core infrastructure for a modern energy economy.

13. Strengthen institutions for whole-of-economy delivery

The scale and cross-cutting nature of the transition call for durable coordination beyond existing arrangements. Establishing an executive body under the Prime Minister's Council on Climate Change as a Low Carbon Development Cell/Secretariat would enable coordination across line ministries and departments, provide continuous analytical support, resolve bottlenecks, and align centre–state action. Five-year sectoral and state budgets aligned to the NDC cycle, modernised regulation, and independent progress assessment will shift climate action to a standing delivery system.

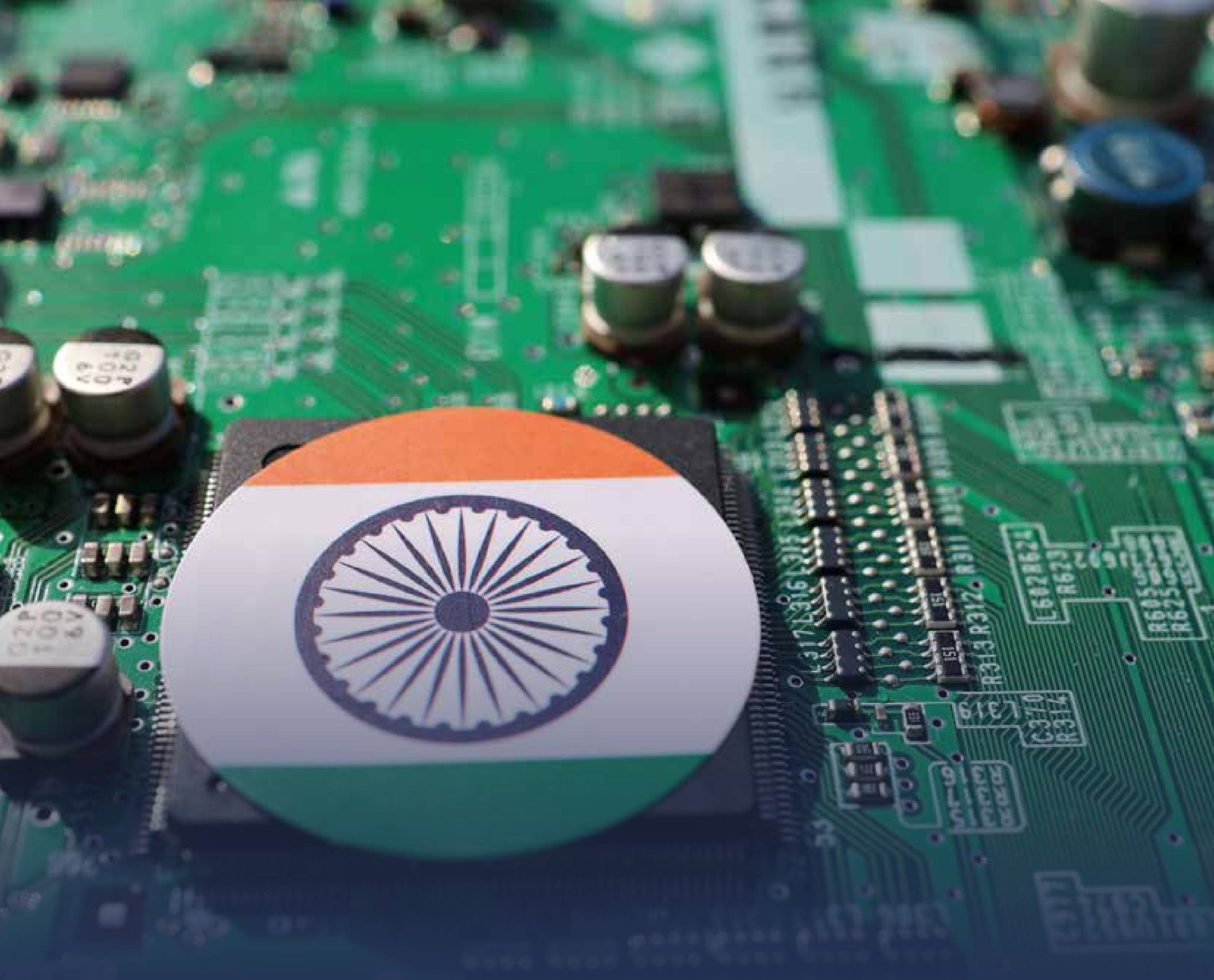
In sum, India's Net Zero transition can be achieved by quickly building the enabling systems that convert sectoral intent into economy-wide action. Demand moderation, electrification, public infrastructure, industrial competitiveness, finance, data, institutions, and people-centred delivery must move together. At the same time, sustained international cooperation through predictable climate finance, technology collaboration, and open, rules-based markets will be essential to support this scale of transformation. Executed well, this agenda positions Net Zero as the foundation of a cleaner, competitive, and resilient *Viksit Bharat*.

Conclusion

India's Net Zero emissions are an opportunity for achieving Viksit Bharat. Building a modern, advanced economy while changing its energy and technological bases is an opportunity for India to leverage the disruption and leapfrog into the future as a leader. It can be the pioneer in the technologies needed for the Net Zero transition. Just as the invention of steam engine led to the Industrial Revolution which transformed past development patterns and economic models, India's Net Zero transition will create new Indian Development Model combining economic vitality, technological leadership, and sustainability. This requires sustained, multi-decade transformation driven with purpose.

Currently, this transition is unfolding amid heightened global uncertainty. Many developed economies have not met earlier climate-finance commitments, or slowed their low-carbon transitions, creating uncertainty about the availability and cost of capital, technology transfer, and future markets for emerging green industries. At the same time, a disproportionate share of impact of climate change is on developing countries, despite their minimal contribution to cumulative emissions.

For India, climate ambition must therefore align with questions of fairness, international cooperation, and the development prerogative. The scale and sequencing of the Net Zero pathway must remain compatible with economic inclusion, structural transformation, and resilience to climate change. The pathways India shows will be a lighthouse for the developing world. The Indian Development Model will set the trend for others.



INTRODUCTION

Introduction

India's Moment of Opportunity: The Viksit Bharat Vision

India stands at a decisive moment in its growth journey. The Hon'ble Prime Minister Shri Narendra Modi has given a call that by 2047, the centenary of Independence, India should become **Viksit Bharat,** a USD 30 trillion developed economy. As articulated by the Prime Minister, this vision is a call for prosperity that reaches every citizen, opportunities that are open to all, and growth that is both sustainable and inclusive.

Already, the world's fourth-largest economy, with a GDP of over USD 4 trillion and a population of approximately 1.46 billion in 2025 (IMF, 2025), India combines a vast domestic market and a powerful demographic dividend. With a median age of 28 years, its young workforce sets the country apart globally (UNFPA 2025). India's development choices therefore carry consequences far beyond its borders. It is an important engine of global growth.

Achieving *Viksit Bharat* will require sustained high growth of 7-8% over the next 25 years, leading to an improvement in the quality of life, employment, housing, education, healthcare, and clean energy access. It will also require moving from informal, low-productivity work to a dynamic, industry and services-led economy that shares the benefits of growth across regions, genders, and income groups.

With approximately 51% of Indians projected to live in cities by 2047, urban planning must deliver liveable, efficient, well-connected spaces with resilient infrastructure and accessible public transport. Investments in education, nutrition, and skills will be equally vital to raise productivity and overall well-being.

None of this is possible without reliable and affordable energy. As India modernises industry, electrifies transport, and raises living standards, energy policy will remain at the heart of the nation's development strategy. For countries at India's stage of development, energy access is foundational to improving human development. Raising the Human Development Index (HDI) depends on ensuring reliable electricity for households, schools, and hospitals, clean cooking fuels, and affordable energy for industries and transport. India's current per-capita primary energy use is just 25–30 gigajoules (GJ) per year, compared to 100–150 GJ per year in Germany or the UK, and more than 250 GJ per year in the US (UNDP, 2023), is low and has tremendous upside potential.

Evidence shows that moving from low consumption levels toward approximately 50–100 GJ per person yields the biggest gains in HDI with better health outcomes, higher life expectancy, longer schooling years, and stronger income growth (Acheampong et al., 2021). At the same time, India need not aspire to the U.S. model of excessive energy consumption. Countries like

Switzerland, Germany, and the UK have achieved high HDI with far more moderate energy use (Pascale et al., 2022). Their experience demonstrates that efficiency and equitable distribution, in energy use are as important as total consumption. Norway's example further illustrates that higher per-capita energy can align with sustainability when sourced from renewable sources.

For India, the strategic path is not just energy expansion but targeted growth in access and infrastructure, combined with investment in efficiency, conservation and sustainable consumption. Mission LiFE (Lifestyle for Environment), conceived by the Prime Minister, and launched by the Government of India, exemplifies this approach. It emphasises sustainable consumption, encouraging individuals and communities to adopt environmentally responsible lifestyles, from reducing energy waste to promoting clean mobility.

India's policy challenge is to increase per-capita energy use two to threefold to maximise HDI benefits. By focusing on universal access, efficient urbanisation, scaling clean power, and mainstreaming Mission LiFE, India can achieve high human development without replicating the unsustainable consumption trajectories of industrialised nations.

India's development choices will define not only its own future but the world's pathway to a just and equitable planet.

Global Climate Responsibility and India's Vulnerability

India's growth ambitions unfold in a world marked by deep inequities in responsibility for and vulnerability to climate change.

India's aspiration to become a developed nation by 2047 is unfolding at a time when climate change is one of the main challenges facing the world. Its impacts are already exacting a heavy toll on human lives, livelihoods, and economies, and causing widespread damage to ecosystems and infrastructure.

The planet has already warmed by approximately 1.3°C compared to pre-industrial times, based on the latest assessments for 2024 and 2025 (WMO, 2024). This warming is largely the result of heavy fossil fuel use by developed countries over the past two centuries. If global emissions continue unchecked, the resulting warming will have grave consequences, more frequent and intense extreme weather events, rising sea levels, and widespread disruption to ecosystems and livelihoods. These impacts will be especially severe for developing countries, which are more vulnerable due to limited resources and less adaptive capacity.

India is especially vulnerable to these risks. More than 80% of the population lives in districts exposed to floods, droughts, heatwaves, cyclones, or sea-level rise (World Bank 2023). These impacts can potentially erode development gains and fall hardest on the poorest communities.

The irony in this vulnerability is that India has contributed very little to the problem itself. The difference in current emissions between countries is stark. On a per-person basis in 2023, the United States has emitted about 17.2 tonnes of Green House Gas (GHG) emissions[i], the European Union 7.2 tonnes, China 9.8 tonnes. As against this, India emitted just 2.9 tonnes, less than half of the global average of 6.7 tonnes (Our World in Data, 2023). This disparity highlights the deep inequities at the heart of the climate crisis, where those who contributed the most historically are often best equipped to adapt, while those least responsible remain most vulnerable.

i Here Greenhouse gas emissions include carbon dioxide, methane and nitrous oxide from all sources including land use change and are measured in tonnes of carbon dioxide equivalent over a 100-year timescale

Science shows that the time left to limit warming to 1.5°C is fast running out. To have a reasonable chance of restricting the temperature increase to 1.5°C, the world's remaining "carbon budget" as of 2025 is estimated at only about 130 to 250 billion tonnes of CO_2, far lower than the 500 billion tonnes assessed in earlier years (Smith et al., 2023). Developed countries have already exceeded their fair share of the global carbon budget. At the annual global emissions rate of approximately 41.6 billion tonnes of CO_2 in 2024 (WMO, 2024), the remaining budget could be exhausted in as little as three to six years, depending on the chosen pathway.

Under the principle of Common but Differentiated Responsibilities (CBDR), first formalised in the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, developed countries pledged to support developing nations through climate finance, technology transfer, and capacity-building. Yet these commitments have largely fallen short, leaving developing countries at a disadvantage as they attempt to manage urgent development needs and climate commitments. These gaps date back to the Kyoto protocol, where several developed countries did not meet their legally binding emission targets or withdrew from commitments altogether. The recent policy reversals, such as the United States' withdrawal from the Paris Agreement in 2017 and its announcement to withdraw again in 2025, have undermined confidence and disrupted momentum. In Europe too, inconsistent implementation of climate commitments has raised concerns. The United Kingdom's recent delays in phasing out gas boilers and internal combustion engine vehicles, as well as Germany's temporary increase in coal use following the energy crisis, have signalled similar wavering of climate resolve. These gaps underline the need for consistent, long-term commitment from those most responsible for the problem, and for stronger international cooperation to support countries like India in achieving both development and climate goals.

India's Development Pathway: Opportunities and Imperatives

India's journey toward prosperity is also a test of how development can happen in a low carbon manner.

India is undertaking a developmental journey with no historical precedent, balancing two goals simultaneously. India has set out a comprehensive development agenda under Viksit Bharat, which envisions increasing GDP to USD 30 trillion by 2047. It involves building the infrastructure, services, and opportunities needed for a better quality of life for all. At the same time, India has voluntarily committed to achieving Net Zero greenhouse gas emissions by 2070. The central challenge is to grow rapidly while progressively reducing emissions, effectively charting a path of low-carbon development. No other large economy has attempted this at a large scale in the past. This transition is further complicated by the fact that many of the technologies needed for Net Zero, such as Carbon Capture Utilisation and Storage (CCUS), long-duration energy storage, and small modular nuclear reactors, remain nascent, expensive and unproven at scale.

Most developed countries peaked their emissions decades ago- Germany, France and the United Kingdom in 1990s; the United States and Canada in 2007; and Japan and Korea in 2020. This gave them a comfortable four to six decades to reach Net Zero by 2050. India, by contrast, has pledged to achieve Net Zero transition in less than 50 years, while simultaneously achieving its developmental goals.

India also has to protect millions of vulnerable citizens from the escalating impacts of climate change. Adaptation is therefore as critical as mitigation, demanding significant investment in resilience and safety nets even under fiscal constraints.

This dual task presents both opportunities and challenges. Given that most of India's future infrastructure is yet to be built, India can embed energy efficiency, resource conservation, and clean technologies, setting itself on a modern, future-ready trajectory. On the other hand, it faces the reality of high upfront costs and competing demands for limited resources.

If India succeeds in demonstrating that rapid economic growth and human development and a low-carbon pathway can advance together, it will set a powerful precedent for other developing nations. India's success will not only shape its own future but also carry global significance in the fight against climate change.

Even though India is not responsible for creating the global problem of climate change, as a responsible nation, it has acted to contribute to solving it. Over the past two decades, India has worked to integrate low-carbon policies in its development. This is led by the Prime Minister's Council on Climate Change (PMCCC) at the national level. At the subnational level, State Action Plans on Climate Change (SAPCCs) are now operational in 34 States and Union Territories, integrating climate considerations into state-level development planning and ensuring that climate action is embedded across all levels of governance.

India has also exhibited committed leadership on the international stage. It has founded platforms like the International Solar Alliance, the Coalition for Disaster Resilient Infrastructure and the Global Biofuel Alliance, bringing together countries to collaborate on shared solutions. Mission LiFE (Lifestyle for Environment) has turned sustainable living into a global people's movement, endorsed by the United Nations and embraced by governments and communities worldwide.

India is also among the few G20 countries on track to meet climate commitments. It has already achieved a 36% reduction in GHG emissions intensity of GDP from 2005 levels and reached 50% non-fossil electricity capacity, ahead of schedule (PIB, 2025). Its per capita emissions remain far below the global average, yet its commitments are among the most ambitious for a country at its stage of development.

While these initiatives have created an essential foundation, they represent only the initial phase of what will need to be a far more extensive and sustained transformation. The most challenging phases of India's transition, such as rapidly scaling clean technologies, ensuring affordability, and building resilience, still lie ahead.

NITI Aayog's Framework for India's Net Zero Transition Pathways

For the first time, India's transition planning unites sectoral expertise and inter-ministerial collaboration under one integrated framework.

In this context, NITI Aayog has undertaken the first government-led, integrated assessment of how India can achieve the vision of *Viksit Bharat* by 2047 while simultaneously achieving Net Zero by 2070. This effort combines sectoral expertise, inter-ministerial coordination, and policy analysis within a unified framework, ensuring that its recommendations are both technically rigorous and actionable. It is important to emphasize that this is a "development first" analysis. The primary focus is on how India can achieve its goal of becoming a developed country. Simultaneously, how India can also contribute to solving the global commons problem of climate change. In that sense, this is not a "decarbonisation" or "mitigation" focused analysis. Instead, the focus is on how India can achieve its developmental goals in a low carbon manner.

As India is attempting a historically unprecedented transition, a detailed examination on all aspects of this transition has been undertaken. Ten Inter-Ministerial Working Groups (IMWGs) were constituted to examine the sectoral and cross-cutting aspects of the transition from power, industry, transport, buildings, and agriculture, to climate finance, critical minerals and the social aspects of the energy transition. Each group brought together policymakers, domain experts, and industry stakeholders to identify challenges, propose actionable policy levers, and highlight synergies across sectors. This synthesis report integrates the findings of the working groups into a coherent national roadmap across two-time horizons, i.e., medium term (to 2050), and the long term (to 2070).

Further, this is designed as a living document, capable of being periodically updated as technologies advance, costs shift, global commitments evolve, and new evidence emerges. This is to ensure that India's Net Zero pathway remains relevant, responsive, and anchored in the latest realities.

The overarching framework for India's Net Zero transition is articulated in the Long-Term Low Emission Development Strategy (LT-LEDS) submitted by India to the United Nations Framework Convention on Climate Change (UNFCCC) in November 2022.

India's low-emission development strategies continue to be guided by the foundational principles of UNFCCC – equity, climate justice and the principle of common but differentiated responsibilities and respective capabilities. Accordingly, as elucidated in its LT-LEDS, India's path to net zero is guided by the following considerations: (i) India's minimal historical contribution to global cumulative greenhouse gas emissions; (ii) the country's substantial and growing energy requirements to support inclusive economic development; (iii) India's commitment to pursuing low-emission development strategies in accordance with national circumstances; and (iv) the imperative to strengthen climate resilience. These considerations inform policy design and implementation to ensure that the transition to Net Zero remains aligned with national development objectives.

The NITI Aayog's ***"A Study Report on Scenarios Towards Viksit Bharat and Net Zero: An Overview"*** is based on modelling approaches that have inherent limitations. This modelling effort has been undertaken to get insights into the potential impacts of mitigation policies, and can be neither predictive nor prescriptive. Given the challenges in modelling the complexities of the real world, all models depend on a range of assumptions, and their outcomes must therefore be interpreted with care and should not be considered as policy prescriptions.

The analysis presented in this study report is subject to multiple uncertainties whose impact on the modelling outcomes has not been quantified. Nor does it incorporate all prospective policy developments and exogenous factors. These include, inter alia, recent, planned and potential future government initiatives, recent and future budgetary allocations, evolving geopolitical dynamics, trade considerations and constraints, and the development and deployment of emerging and disruptive technologies. As these factors may materially influence India's energy emissions and development trajectories, this report should be considered one of several studies rather than a prescriptive or exhaustive pathway to net zero emissions.

The options presented in this report are in the context of India's long-term vision to achieve Net Zero emissions by 2070. However, this vision was itself presented in the context of a unified global effort to address the problem of global warming on the basis of the agreed principles of equity and common but differentiated responsibilities and respective capabilities. For the required pace of technological development and deployment to materialize at scale, it is necessary that the projected technologies finally emerge into the real world of deployment at scale. Further, to deploy new technologies at scale, even after their development, a conducive, cooperative global environment is necessary. The pace and feasibility of achieving Net Zero emissions are also critically dependent on the availability of adequate means of implementation, viz., finance, technology, and capacity-building support from developed countries, consistent with India's development priorities and national circumstances, as underlined in the UNFCCC and its Paris Agreement, to both of which India is a signatory. Furthermore, external and unpredictable events beyond government and indeed the nation's control may alter projected pathways. Key macroeconomic and other assumptions underpinning the analysis, including GDP growth and population projections, are inherently uncertain and may diverge from future outcomes.

This report has been prepared as an independent analytical study on *Viksit Bharat @2047* and Net Zero. It is intended solely to support research and policy dialogue, and is an initial step to encourage further discussion on this issue at the national level. The contents of this report do not represent, and shall not be construed as, the official views, positions, commitments, or policy directions of the Government of India, any Ministry or Department, or any national or international institution. Nothing in this report shall be interpreted as legal, financial, investment, or policy advice, nor as creating any obligation, commitment, or expectation on the part of any government, public authority, or private entity. Thus, in view of the above, the findings and outcomes of the study provide an indicative direction in which technological, financial and capacity building measures need to be undertaken to steadily move towards the goal of Net Zero.

The report is structured as follows:

i. **Chapter 1: India's Energy, Economy, and Climate-The Current Landscape:** Provides the economic and social baseline, current energy and emissions trends, and progress under existing energy and climate policies.

ii. **Chapter 2: Integrated Modelling Framework for Net Zero Pathways:** Explains the modelling approach and tools used, defines scenarios, and summarises sector-wise projection methods.

iii. **Chapter 3: Framing India's Century: The Viksit Bharat Vision and Sustainable Choices** chapter sets out the vision framework, India's strategic endowments, the macroeconomic blueprint, and sectoral development choices that drive demand.

iv. **Chapter 4: India's Transition Pathways:** Presents national-level projections for final and primary energy demand, electricity demand and supply. It also highlights key levers for enabling low-carbon transition.

v. **Chapter 5: Sectoral Transition Pathways:** Details pathways for transport, industry, buildings, agriculture, and waste, outlining key technologies and policy levers.

vi. **Chapter 6: Financing Net Zero Pathways for India:** Estimates investment needs for mitigation, maps aggregate financial flows and the financing gap, and proposes measures to mobilise finance.

vii. **Chapter 7: Macroeconomic Implications of Net Zero:** Analyses the impact of the Net Zero transition on GDP and its components, sectoral output and shares, investment, trade, household income and consumption, fiscal indicators, regional dynamics, and the import bill/government revenue.

viii. **Chapter 8: Critical Minerals and Supply Chains:** Examines critical mineral requirements, supply-chain risks, enabling policies, circular-economy solutions and R&D needs.

ix. **Chapter 9: India's Energy Transition: A Social and Behavioural Blueprint:** Addresses land and water needs, employment and migration, health vulnerabilities and co-benefits, and behavioural patterns, barriers, and opportunities for change.

x. **Chapter 10: Enabling the Net Zero Transition: Challenges and Opportunities**—Consolidates sectoral and cross-cutting challenges and recommendations, and outlines the way forward to Net Zero.

Together, these chapters chart a framework for India's path to a developed, low-carbon future. Chapter 1 opens by framing the dual challenge: delivering prosperity for all while committing to Net Zero by 2070, and defining the baseline for the economy, energy system, and climate policy from which the transition will unfold.

1

INDIA'S ENERGY, ECONOMY, AND CLIMATE- THE CURRENT LANDSCAPE

India's Energy, Economy, and Climate-The Current Landscape

1

This chapter sets the stage for India's pathway to Net Zero by 2070, examining the nation's economic ambitions, social realities, and the central role of energy in shaping growth. It explores how India balances rapid development with low-carbon pathways, tracing current energy supply and demand patterns, emissions trends, and the evolution of climate policy. Together, these insights form the baseline against which India's transition to Net Zero needs to be understood.

1.1 OVERVIEW

India's economy has expanded from under USD 300 billion in 1993 to nearly USD 4.2 trillion in 2025 (IMF 2025), making it the world's fourth-largest economy in nominal terms and third-largest by Purchasing Power Parity (PPP) (PIB, 2025). Per-capita income has grown more than eightfold, from USD 305 in 1991 to USD 2,700 in 2024. More than 250 million people have exited multidimensional poverty between 2015 and 2022 (NITI Aayog 2023; UNDP).

These achievements rest on deep structural reforms, ranging from Goods and Services Tax (GST) and the Insolvency and Bankruptcy Code to the creation of Aadhaar and the Unified Payments Interface (UPI), all of which have reshaped India's growth model around physical and digital infrastructure, and improved service delivery. Yet, sustaining this transformation depends critically on reliable, affordable and clean energy.

Energy and development remain deeply intertwined. Every phase of economic expansion, from industrialisation to urbanisation and rising household prosperity, has been accompanied by an increase in energy demand. According to MOSPI Energy Statistics 2025, India's primary energy supply (excluding traditional biomass) rose from 28.4 exajoules (EJ) in 2014–15 to 38.4 EJ in 2023–24, an increase of more than 30%. At the same time, energy intensity of GDP declined from 0.27 MJ per INR to 0.22 MJ per INR, showing that India has begun to decouple economic growth from energy use even as total demand expanded. This balancing act, expanding demand while lowering intensity, captures the essence of India's energy- development nexus.

Yet the composition of this energy use highlights the scale of the challenge. In 2024-25, fossil fuels provided about 87% of total primary energy supply (41.45 EJ[ii]): coal accounted for 54%, oil 26%, and gas 7%. Non-fossil sources contributed 13% of total primary energy, out of which bioenergy (including traditional biomass) accounting for 8% with nuclear, hydro, solar, and wind making up the rest.

ii The difference with respect to MoSPI estimations arises from the accounting of traditional biomass

India is among the countries with the fastest renewable energy expansion. Non-fossil fuel-based installed capacity has reached 50% of the grid-based total power installed capacity (MNRE, 2025). Universal household electricity access was achieved in 2021 through the Saubhagya program, while over 80 million families gained access to clean cooking fuel under the Ujjwala Yojana. Efficiency initiatives, from Unnat Jyoti by Affordable LEDs for All (UJALA) program to Bureau of Energy Efficiency's Perform, Achieve and Trade scheme for industries, have cut costs, reduced emissions, and improved household welfare.

In short, while the aggregate energy mix is still dominated by fossil fuels, the foundations of a more diversified, inclusive, and lower-carbon energy system are firmly in place.

Climate policy has evolved in tandem with this transformation. The first phase, anchored in the National Action Plan on Climate Change (2008), emphasised co-benefits: reducing fuel imports, improving air quality, and enhancing rural livelihoods through missions on solar, energy efficiency, and sustainable agriculture. Under the Paris Agreement (2015), India pledged to reduce GHG emissions intensity by 33–35% from 2005 levels, and achieve 40% non-fossil power capacity, and expand forest sinks (UNFCCC). In August 2022, India enhanced its NDCs raising the emissions-intensity target to 45% by 2030 from 2005 levels, and the non-fossil installed-capacity target to 50% by 2030. India achieved revised target of 50% non-fossil installed capacity in 2025, while emissions intensity had fallen by 36% between 2005 and 2020 (BUR-4, 2024).

The second phase began with India's Panchamrit commitments at COP26 and was later consolidated in the Long-Term Low-Emissions Development Strategy (PIB, 2021; GoI, 2022). Together, these shifted India's climate policy to a comprehensive low-carbon development pathway. These international pledges have been reinforced domestically through the recognition of "green growth" as a core development priority in the Union Budget 2023-24 (Ministry of Finance, 2023).

Importantly, India has framed its climate ambitions within the principles of climate justice and Common but Differentiated Responsibilities (CBDR), asserting that its path must reconcile energy transition with economic growth, poverty eradication, job creation, and energy access.

The next section turns to India's economic and social context, exploring how structural transformation, demographics, and urbanisation interact with this energy–development nexus.

1.2 ECONOMIC AND SOCIAL CONTEXT

Sustained High Growth, Global Repositioning

Over the past decade, India has consistently ranked as the fastest-growing large emerging economy. Between 2015 and 2024, India's real GDP growth remained within a consistently high band of 6.5% to over 9%, excluding the pandemic period. This clearly outpaced other large emerging economies such as Indonesia (around 5%), Malaysia (4-5%), and the Philippines (5-6%), though it trailed China's rapid expansion in the early 2010s (see Figure 1.1).

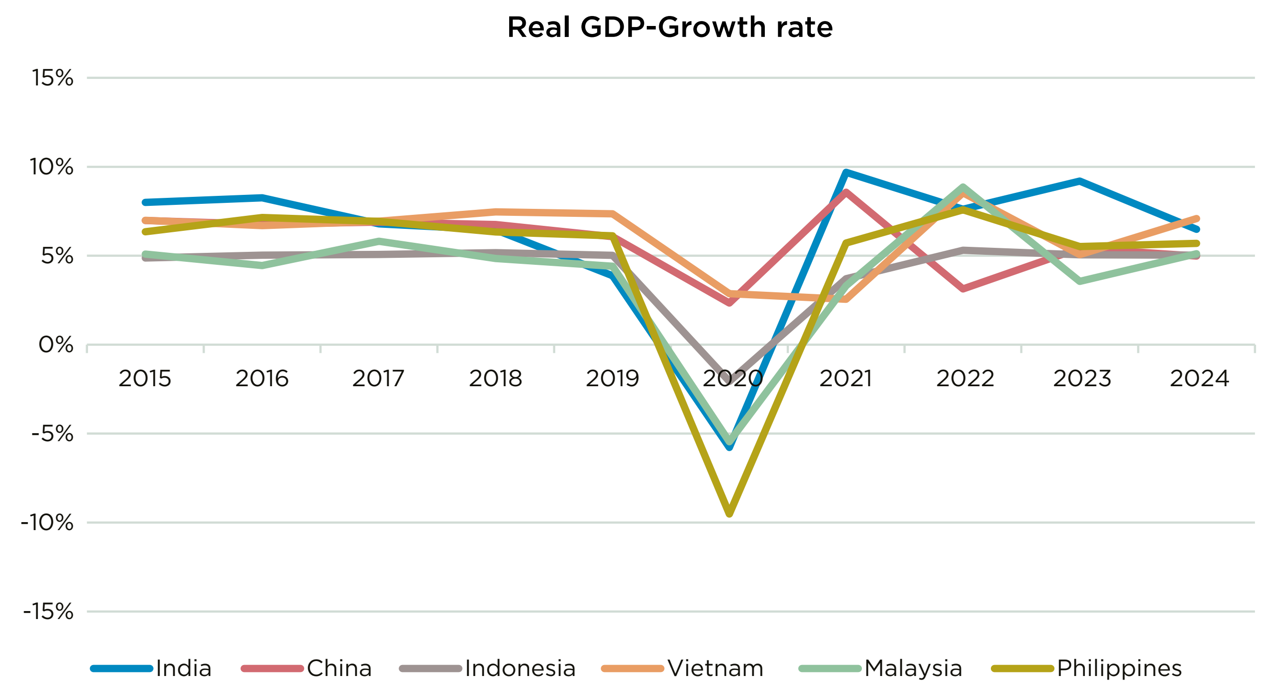


Figure 1.1: Real GDP growth rate of select countries (2015 – 2024)

Source: *World Development Indicators, World Bank*

This rapid expansion translated into steady gains in nominal economic scale and global GDP rankings. In 2011, India's nominal GDP was USD 1.8 trillion and ranked tenth globally. India became the 7th largest economy by 2015, and in 2022, it overtook the United Kingdom to become the fifth-largest economy, and by 2025 surpassed Japan to claim the fourth position. India ranks behind only the United States (USD 30.5 trillion), China (USD 19.2 trillion), and Germany (USD 4.8 trillion) (See Figure 1.2).

This ascent, from tenth to fourth place in just fourteen years, reflects the combined impact of sustained growth, macroeconomic stability, and structural reforms. It has also translated into a growing global footprint: between 2015 and 2025, India contributed nearly 15% of incremental world GDP growth, second only to China (32.1%) and ahead of advanced economies such as the United States (9.4%) and the European Union (World Economics, 2024). Few countries have managed a comparable scale of contribution through a decade marked by pandemic disruptions, commodity volatility, and geopolitical tension.

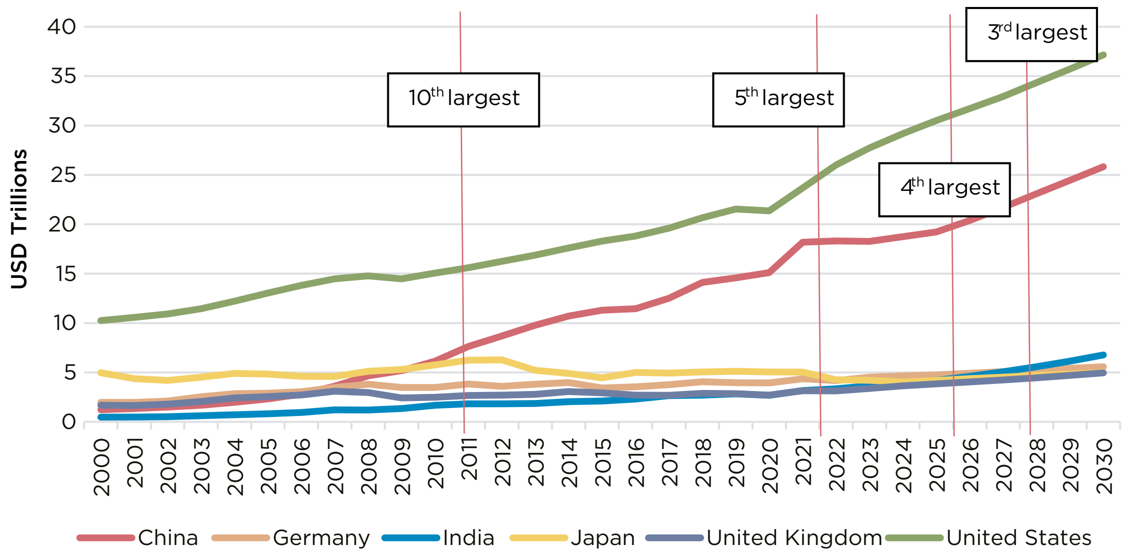


Figure 1.2: Nominal GDP of select countries in USD Trillions (2000 – 2024)

Source: *IMF*

These macroeconomic gains have translated into tangible social outcomes. Between 2015 and 2022, more than 250 million people were lifted out of multidimensional poverty, with the Multidimensional Poverty Index (MPI) headcount ratio falling from 29% to 11% (NITI Aayog, 2024; UNDP). By 2019, near-universal residential electricity access was achieved through the Saubhagya scheme, while over 100 million poor households gained Liquified Petroleum Gas (LPG) connections under the Pradhan Mantri Ujjwala Yojana (PMUY) (PIB, 2025). More recently, the PM JanMan initiative has extended energy, housing, and water services to vulnerable tribal groups (PIB, 2024).

Investment Led Model

Analysis of the Reserve Bank of India database on Capital, Labour, Energy, Materials and Services confirms that India's growth since 2000 has been powered primarily by capital deepening. Between 2000–10, capital stock expanded by 8.1% annually on average, far outstripping the contributions from employment (2.8%), labour quality (0.6%), and Total Factor Productivity (TFP) (0.2%). The following decade (2010–20) saw a similar pattern: capital stock growth (7.7%) remained the largest driver, while TFP made only a modest contribution (0.6%). In the most recent period (2021-24), capital accumulation slowed to 5.7%, but employment growth picked up slightly[iii].

Macroeconomic stability has underpinned India's investment-led growth. Public debt is roughly 80% of GDP, yet external debt is modest at 18.7% of GDP (Ministry of Finance, 2024) and predominantly long-term in nature. Inflation has averaged within the RBI's 4-6% tolerance band, even amid global commodity spikes, supported by proactive food price management and targeted energy subsidies. Foreign exchange reserves exceeding USD 600 billion provide a strong buffer, covering short-term liabilities and shielding the economy from external shocks.

iii https://www.rbi.org.in/scripts/klems.aspx

India's development trajectory has been shaped by the distinctive structure of its economy. According to the Periodic Labour Force Survey 2023-24, nearly 46% of the workforce is in agriculture, generating about 14.7% of Gross Value Added (GVA) in 2023-24. This underscores the sector's importance but also the significant productivity gap relative to the rest of the economy. Manufacturing share is around 18%, which highlights the substantial opportunity to expand labour-intensive and high-productivity industry, as has been observed in successful transformation stories globally (China--25% & Vietnam--24%). Meanwhile, services contribute 55% to Gross Value Added (GVA) while employing 30% of the workforce reflecting their central role in output but their more limited capacity for large-scale labour absorption. Compounding this is the dominance of informality: over 70% of non-farm workers are in informal jobs (PLFS 2023-24). Female labour force participation, though rising to 42% in 2023-24, remains concentrated in agriculture and low-productivity informal work, and continues to trail global and emerging-economy benchmarks (MosPI, 2024).

Recognising the limits of only services-led growth, the government over the past decade has placed renewed emphasis on manufacturing revival and infrastructure-led expansion. The Production-Linked Incentive (PLI) schemes and the National Manufacturing Mission (NMM) have targeted strategic sectors such as electronics, pharmaceuticals, automotive, textiles, and clean energy technologies. This industrial policy push has been complemented by a sustained increase in public investment.

Between FY2016-17 and FY2025-26, public capital expenditure more than tripled, from ₹4.5 lakh crore (2.9% of GDP) to ₹15.5 lakh crore (4.3% of GDP), according to the Union Budget 2025. The outcomes are visible: national highways expanded by over 60%, metro rail networks grew nearly fourfold (from 250 km to 930 km across major cities), 1,400 km of dedicated freight corridors became operational, and BharatNet brought broadband to almost every gram panchayat (MoHUA, 2024).

Box-1.1: Performance Linked Incentive (PLI) Scheme and National Manufacturing Mission (NMM): Design and Impact Snapshot

The Production Linked Incentive (PLI) scheme is a time-bound, pay-for-performance programme that rewards incremental sales of goods made in India to catalyse capital expenditure (capex), jobs, and technology transfer leading to higher exports. Launched in 2020 and now spanning 14 sectors with an outlay of ₹1.97 lakh crore, it has 806 approved applications. As of March 2025, realised investments are ~₹1.76 lakh crore; participant sales have crossed ~₹16.5 lakh crore; and over 12 lakh jobs (direct and indirect) have been generated, indicating deeper domestic value addition and a stronger export orientation.

Complementing PLI, the National Manufacturing Mission (NMM) announced in Union Budget 2025–26, aims to boost innovation, raise competitiveness, and expand manufacturing capacity across priority sectors, aligned with the Make in India and the Aatmanirbhar Bharat initiatives. It emphasises faster technology adoption and deeper MSME integration into value chains; the Government has also flagged rapid progress and a "higher value at lower price" ethos for Indian industry.

Sectoral gains are tangible: electronics output rose by 146%, from ₹2.13 lakh crore (FY21) to ₹5.25 lakh crore (FY25); the automobile and auto-components PLI saw ₹67,690 crore committed, ₹14,043 crore invested, and ~28,884 jobs created (as of Mar 2024); and solar PV tranches target ~48 GW of integrated capacity with ₹48,120 crore committed and ~38,500 direct jobs projected (to 30 Jun 2025). Together, these illustrate how PLI is shifting India from assembly-led manufacturing to competitive, scaled production across priority value chains.

Ref PIB https://www.pib.gov.in/PressNoteDetails.aspx?NoteId=155082&ModuleId=3
https://www.pib.gov.in/FactsheetDetails.aspx?Id=149250

Stability and Resilience Amid Global Shocks

During the global energy crisis of 2021–22, when households across Europe faced record electricity and gas price spikes (IEA, n.d), India pursued a consumer protection strategy rather than full price pass-through. The government cut central excise on petrol and diesel in two tranches (November 2021 and May 2022) by ₹13/litre for petrol and ₹16/litre for diesel (Ministry of Petroleum and Natural Gas, 2025), and these reductions were fully passed on to consumers. State Value Added Tax (VAT) reductions in some states added relief. LPG subsidies were similarly expanded. Though India imports about 60% of its LPG, the effective price of a 14.2 kg domestic cylinder for Pradhan Mantri Ujjwala Yojana (PMUY) consumers was reduced from ₹903 in August 2023 to ₹503 in February 2025 (after a targeted subsidy of ₹300) (Ministry of Petroleum and Natural Gas, 2024). Together, these measures show that India was able to avoid the worst consumer-side disruptions seen in many countries, thanks to excise and subsidy relief and tariff regulation, reinforcing the policy that energy affordability is a developmental priority.

Comparative Position: Strengths and Exposures

Comparative indicators highlight both India’s strengths and vulnerabilities (Table 1). On the macro side, India has outperformed lower-middle-income peers in per-capita GDP and investment, but it remains below Upper Middle-Income Country (UMIC) and High-Income Country (HIC) benchmarks. Its favourable demographics contrast with low urbanisation. Structurally, agriculture still accounts for a disproportionate share of employment, manufacturing lags, and labour productivity is less than half the UMIC average. Social gains in schooling and poverty reduction are notable, but health spending remains low. Innovation and R&D intensity are weak compared to UMICs and HICs, though digital diffusion is progressing rapidly. External stability, by contrast, is relatively strong, with high reserve cover and manageable debt ratios.

Table 1.1: Comparative socio-economic indicators — India vs. country income groups (2022–24)

	India	Lower Middle Income	Upper Middle Income	High Income
Macro indicators				
Per-capita GDP (Current USD)–2024	2696.7	2517.6	10,961.8	50,443.9
Merchandise trade (% of GDP)-2024	29.2%	43.8%	40.4%	45.6%
Gross fixed capital formation (% of GDP)-2024	29.6%	28.6%	33.4% (2023)	22.2%
Demographics				
Population aged 15-64 (% of total population)-2024	68.2%	64.2%	68.4%	64.7%
Urban population (%)-2024	36.8%	40.9%	69.3%	81.3%
Structural balance of GDP				
Agriculture (%Value added, %employment)-2023	16.1%, 43.5%	15.4%, 39.1%	6.9%, 20.4%	1.3%, 3.2%
Manufacturing (% Value added)-2024	12.5%	14.2%	21.2%	12.4%
Female labour force participation rate-2023	41% (2024)	37.5%	-	55.1%
GDP per person employed (constant 2021 PPP USD)-2024	24,468	22,178	45,477	119,252
Social indicators				
Gross Secondary School enrolment rate (%) -2023	78.9%	67.9%	95.6%	103.6%
Government expenditure on education (% of GDP)-2022	4.1%	3.5%	3.7%	4.8% (2021)
Current Health Expenditure (% of GDP)-2022	3.3%	3.9%	5.6%	12.5%
External Stability				
Total reserves (% of external debt)-2023	97%	54.9%	82.3%	-
Short-term debt (% of total external debt)-2023	19.5%	16.2%	30.9%	-
Innovation capacity				
R&D expenditure (% of GDP)-2022	0.67%	-	2.14%	2.9%
Annual patent applications per million people-2021	19	8(Egypt), 11 (Vietnam)	22(Brazil), 29 (South Africa)	790 (US), 479 (Germany
Researchers in R&D per million-2020	259	-	1283	4238
High-technology exports (% of manufactured exports)-2023	14.9%	15.7%	22.1%	23.45%

	India	Lower Middle Income	Upper Middle Income	High Income
Individuals using internet (% of population)	56% (2022)	54%	78.5%	93.4%
Firm level inclusiveness				
Firms with at least 10% foreign ownership-2024	0.65% (2022)	11.6%	8.6%	9.1%
Firms with female participation in ownership (% of firms)-2022	3.88% (2022)	29.5%	35.9%	40.1%
Energy and Climate				
Energy use (kg of oil equivalent) per USD 1,000 GDP (constant 2017 PPP)-2022	82.87	76.5	107.1	70.94
GHG Emissions per capita (kgCO_2e per capita)- 2024	2.9	2.9 (Egypt), 5.8 (Vietnam)	13.2 (Brazil), 8.5 (South Africa)	17.2 (US), 7.8 (Germany)

Source: *World Development Indicators, WIPO, OurWorldinData*

Perhaps most importantly, India's energy and climate indicators underline both progress and exposure. The per capita GHG emissions are among the lowest in the world.

The high import dependence (89% for oil and 47% for natural gas) expose India to risk of external supply disruptions and price shocks (MoSPI, 2025). These vulnerabilities echo cautionary tales from upper-middle-income countries (UMICs) such as Brazil and South Africa, which stagnated after reaching middle-income status due to structural rigidities, commodity dependence, and inequality. India's demographic dividend, digital depth, and fiscal prudence set it apart, and by now focusing on productivity in manufacturing and modern services, India is on the cusp of sustained growth to becoming a developed country i.e., Viksit Bharat by 2047.

1.3 ENERGY AND EMISSION PROFILES

Global Energy Trends

World primary energy use rose from 550.5 EJ in 2015 to 592.2 EJ in 2024, an average growth of 0.8% per year. This is modest relative to global GDP expansion but still added 42 EJ — almost the size of the EU's entire annual hydrocarbon consumption in 2024. Crucially, the global system remains fossil-fuel dominant: in 2024, coal, oil, and natural gas together still supplied 87% of total energy, virtually unchanged from 2015 despite doubling of renewables' share and nuclear inching up.

Notwithstanding the global average, the national trajectories show variance. The EU's total energy use fell from 68.3 to 52.0 EJ (2.9%/yr decline), and the US decreased from 95.5 to 91.8 EJ (decline of 0.4%/yr). This reflected mature energy demand and efficiency gains. However, both the EU and the US still meet most of their demand from fossil fuels. While the share of coal is lower than a decade ago the share of gas has increased. China's consumption expanded from 126.2 EJ to 158.9 EJ (increase of 2.6%/yr). Coal's share has decreased while oil, gas, nuclear and renewables have increased. India's consumption grew from 29.3 EJ to 38.8 EJ (+3.2%/yr increase). The energy mix is dominated by fossil fuels at 87%, with coal remaining the main source (See Figure 1.3) (BP, 2016; KPMG, 2025[iv]).[v]

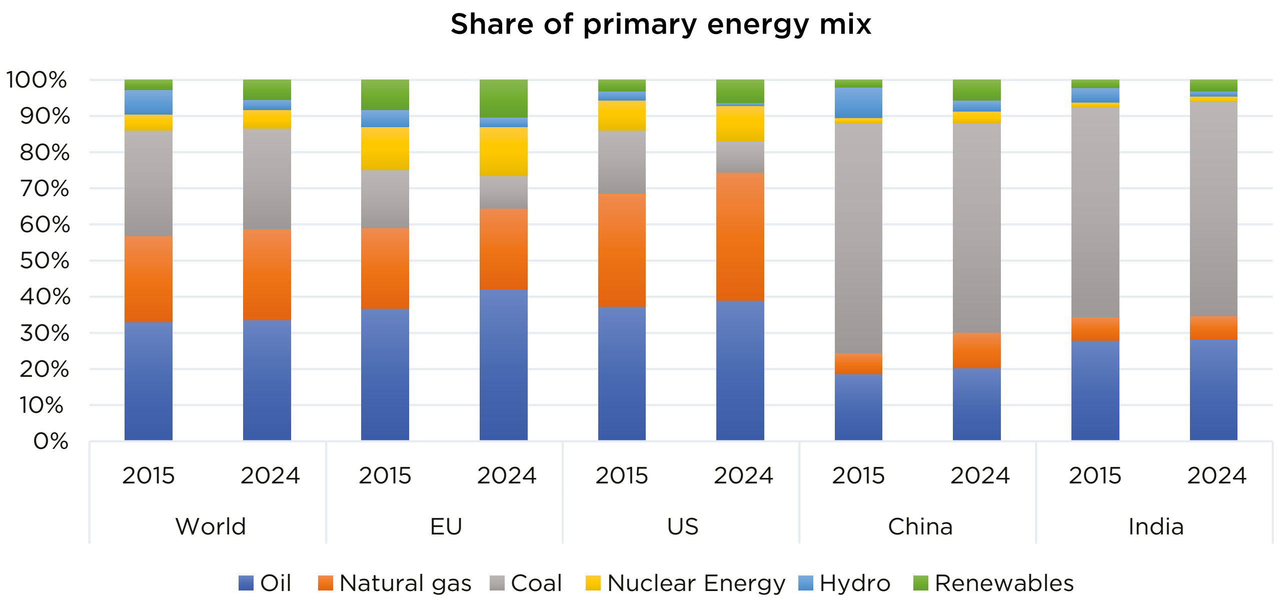


Figure 1.3: Comparative share of primary energy mix of select countries between 2015 and 2024 (BP, 2016; Energy Institute KPMG, & Kearney, 2025)

India's Energy Mix

Globally, the headline is clear: even as renewable energy has significantly scaled, fossil fuel dominance continues. India now stands out as the fastest-growing large energy consumer. India's energy system is diversifying. As of May, 2025, installed power generation capacity was 476 GW. Non-fossil sources contributed about 50% of this, while coal accounted for 46%. Coal supplied 73% of the total power generation; non-fossil sources contributed roughly 25% (See Table 1.2).

iv 2015 numbers taken from BP Statistical review of world energy 2016, and 2024 numbers used from KPMG Statistical review of world energy 2025

v Due to different methodologies, there is a small difference in comparison with MoSPI estimates which shows primary energy at 28.4EJ in 2015 and 38.4 EJ in 2024 for India

Table 1.2: Current status of electricity capacity and generation in India (2025) (BU) (2024-25) (utility-based)

	GW	%	BU	%
Coal	221.8	46.68%	1332	72.89%
Oil & Gas	25.12	5.29%	32	1.75%
Nuclear	8.18	1.72%	57	3.12%
Hydro	47.73	10.04%	149	8.15%
Solar	105.64	22.23%	144	7.88%
Wind	50.04	10.53%	83	4.54%
Bio Power	11.58	2.44%	13	0.71%
Small Hydro	5.1	1.07%	12	0.66%
Import	-		5.5	0.30%
Total	475.19	100.00%	1827.5	100.00%

Source: *CEA, 2025; ICED Dashboard NITI Aayog*

Renewables now dominate new additions and are reshaping the structure of the power system. However, their low-capacity utilisation means far more capacity must be built to meet demand. Meanwhile, maintaining real-time balance between supply and demand becomes increasingly complex as variable generation grows.

To manage this transition, energy storage, flexible generation, and stronger transmission and distribution networks will need to scale rapidly. Coal continues to provide dependable, cost-effective baseload power, anchoring system reliability as cleaner sources expand.

Taken together, a rapid clean build-out atop a coal-heavy base, this frames India's central task: sustain growth while accelerating efficiency and diversification so rising energy demand does not hard-lock higher emissions or import risk. The pace of that shift is best assessed relative to output, hence the turn to energy intensity.

Energy Intensity and Efficiency Gains

Energy intensity of GDP trends reinforce this picture. Globally, energy use per unit of output fell from about 142 kg oil equivalent per USD 1,000 GDP in 1990 to 90 in 2022 (constant 2021 PPP), a 37% improvement (World Bank). India's decline has been even sharper: from 147 to 82.9 kg oil equivalent per USD 1,000 GDP, a 44% drop, reflecting efficiency gains and structural shifts.

By comparison, the United States stands at 89.5 kg oil equivalent per USD 1,000 GDP, the European Union at 54.4, and high-income economies average around 80.2. India thus still uses more energy per unit of GDP than some advanced economies, but is converging quickly and already performs better than the upper-middle-income average (107 kg of oil equivalent per USD 1,000 GDP). In short, growth has become partly decoupled from energy use.

These gains in efficiency set the context for India's emissions profile, where absolute emissions are still rising, but per-capita and intensity indicators remain comparatively low.

India's Greenhouse Gas (GHG) Emissions Profile

India's GHG emissions reflect both its developmental stage and structural energy choices. In 2024, per-capita net GHG emissions were 2.9 tCO_2 (including land-use), less than half the world average of 6.7 t, and far below countries such as China, other upper-middle-income economies, or the United States (see Figure 1.4) (Ritchie, 2023). India remains one of the lowest per-capita emitters among large economies despite being the fastest-growing major energy consumer.

In absolute terms, based on *MoEFCC* inventories, between 2000 and 2020, energy-sector emissions more than doubled, industrial process and product use (IPPU) nearly tripled, while agriculture and waste emissions rose modestly (see Figure 1.5). Land Use, Land Use change and Forestry (LULUCF) continued to be a net sink. According to the government's latest *Biennial Update Report* (BUR) (2020 base year), total gross GHG emissions (excluding land use) were about 2.96 $GtCO_2e$ and net emissions about 2.44 $GtCO_2e$ after accounting for land use sinks.

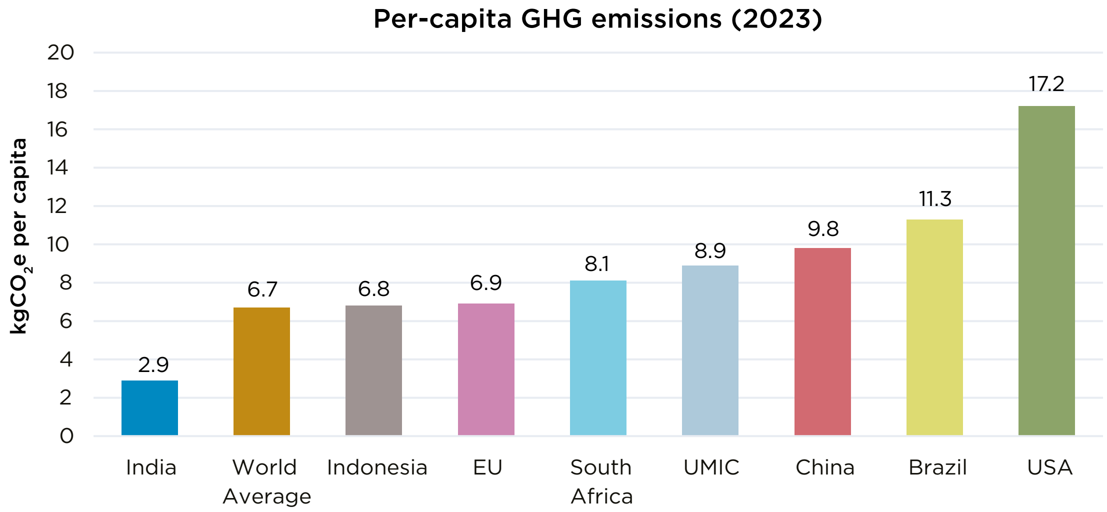


Figure 1.4: Per-capita GHG emissions of select countries in 2023 (tonnes per capita)

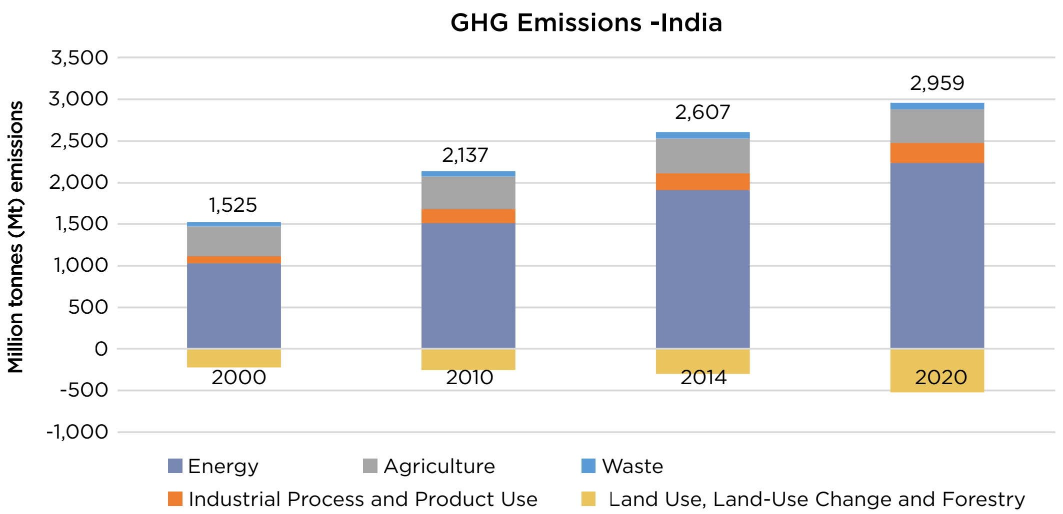


Figure 1.5: India's GHG emissions trend for 2000 to 2020

Source: *Biennial Updated Report*

At the same time, India has already reduced its emissions intensity of GDP by about 36% between 2005 and 2020, surpassing its original Paris Agreement target well ahead of schedule.

Taken together, these numbers highlight India's low per-capita emissions, declining carbon intensity, with a coal-heavy power system that anchors industrial and residential energy supply. The speed of clean-electricity expansion and industrial low-carbon growth will therefore determine the pace of India's overall transition.

To understand how energy is consumed across the economy, it is important to examine sectoral demand patterns.

Sectoral Patterns of Demand in India

Over the last decade, final energy consumption in India rose from 414 Mtoe in 2014 to 614 Mtoe in 2024, about 38% increase. (MoSPI, Energy Statistics 2025). The industrial sector showed the highest growth (13%) driven by metals, cement, chemicals, and other energy-intensive industries (see Figure 1.6). The transport sector followed with 11% growth, driven by road freight expansion and a rising vehicle stock. Buildings (residential, commercial and public), continued a steady increase. Universal electricity access, rising appliance ownership, and expanding floor space pushed electricity consumption, especially for lighting, cooling and small motors. Agriculture and other uses remain smaller in absolute terms but locally significant through diesel use for irrigation and rural mobility.

These patterns underline India's core transition task: not just expanding clean supply, but steering demand growth particularly in industry, transport, and buildings towards efficiency and deeper electrification. This is to ensure that rising energy use does not translate into proportionate increases in emissions or import dependence.

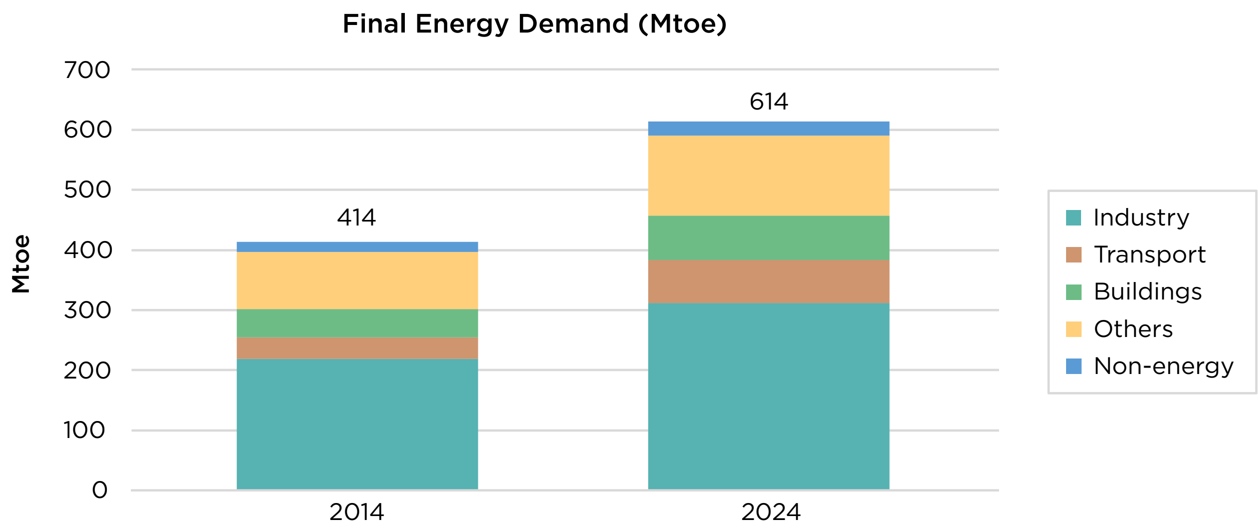


Figure 1.6: India's final energy demand and sectoral share for 2014 and 2024 (Million tons oil equivalent, Mtoe)

On a per-capita basis, India's electricity consumption remains modest despite recent gains. In 2024, India consumed about 1,400 kWh per person, well below the world average (3,780 kWh) and also below other countries such as South Africa (3,825 kWh), EU (6,000 kWh), and the US (12,700 kWh) (Ritchie, 2023).

This signals substantial headroom for demand electrification, from Electric Vehicles and modern cooking, to low-temperature industrial heat. The policy imperative is enabling rapid electrification while simultaneously greening the power supply, ensuring that incremental demand raises productivity and living standards without locking in higher emissions or import risks.

Energy and Human Development

Access to modern energy is directly correlated with human development outcomes. Cross-country work and sectoral studies show that households and communities with reliable electricity and clean cooking access consistently achieve higher schooling, improved health indicators, and greater household incomes. However, the extent of these benefits varies by context and complementary investments such as roads, appliances and credit availability.

The United Nations Development Programme (UNDP) has long recognised energy as an enabling capability, documenting strong associations between modern energy access and higher Human Development Index (HDI) levels, particularly once a basic threshold of access is crossed (Gaye, 2008). The report Tracking SDG 7, 2024, echoes this pattern: expanding access to electricity and clean cooking correlates with improved education, health, and poverty reduction, yet progress remains off-track without greater investment.

According to the *Human Development Report 2023-24*, India's HDI stood at 0.644, placing it within the medium human development category. An office of the Principal Scientific Adviser (PSA) report envisions India climbing to the *high HDI* range (0.7–0.79) and eventually the *very high HDI* range (0.80+), which could require per capita energy use of 41.2–48.6 gigajoules (GJ) per year (Indian Institute of Management Ahmedabad, 2024). This is significantly below the historical global average of ~100 GJ/capita observed in 1975, reflecting efficiency and technology improvements.

In comparative perspective, India's HDI of 0.69 at just 27 GJ per capita places it near the lower end of the global energy–development curve. Peers such as Brazil and South Africa achieve modestly higher HDI levels with two to three times India's energy use. Advanced economies cluster above 0.9 HDI, yet their energy intensities diverge widely, from ~135 GJ in Germany to ~360 GJ in Norway, illustrating that once high development levels are reached, additional energy use yields diminishing returns (see Figure 1.7).

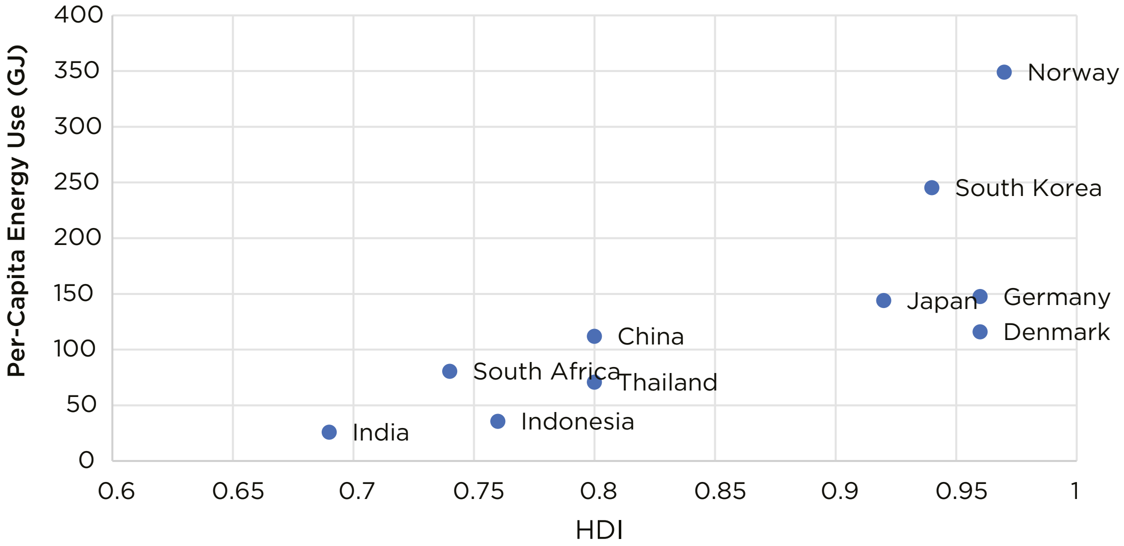


Figure 1.7: HDI Correlation with per-capita energy use

This comparison suggests that India could advance into the *high HDI* category with only a moderate increase in per capita energy use (≈40–50 GJ), provided the transition is driven by efficiency gains. The overall pattern underscores that India can achieve higher human development without converging to the very high energy intensities of advanced economies.

The next section examines India's policy and institutional architecture, examining how national strategies, sectoral programmes, and global commitments are shaping the speed and direction of the transition.

1.4 POLICY DEVELOPMENTS AND INSTITUTIONAL ARCHITECTURE

India's evolving economy-energy-climate landscape is marked by an ambitious and comprehensive policy architecture, reflecting the nation's dual imperative: achieving rapid, inclusive economic development while honouring domestic and international climate commitments. The release of the Long-Term Low-Emissions Development Strategy (LT-LEDS) to the UNFCCC, alongside a suite of updated sectoral policies and institutional mechanisms, signals a decisive shift toward a coordinated, whole-of-economy low-carbon transition.

1.4.1 Policy Evolution

India's policy and institutional architecture has unfolded in phases over the past two decades. What began as a set of co-benefit-oriented strategies has gradually expanded into a comprehensive framework that integrates long-term climate goals with economic development priorities (Figure 1.8).

Phase I (2008–2015):
Co-benefits Framing

India's early climate actions were embedded in development programs and presented as win-win "co-benefits." This approach underpinned India's voluntary pledge at Copenhagen (2009) to reduce the emission intensity of its GDP by 20–25% by 2020 (compared to 2005 levels), avoiding absolute emission caps that might hinder growth. Central to this was the National Action Plan on Climate Change (NAPCC), launched in 2008, which, through eight National Missions, provided a foundational structure for sectoral mitigation and adaptation goals. The missions spanned solar energy, enhanced energy efficiency, sustainable habitat, water, sustainable agriculture, Green India (forests), the Himalayan ecosystem, and strategic climate knowledge. Several of these missions, particularly on water, agriculture, forests, and the Himalayas were explicitly aimed at strengthening adaptive capacity and climate resilience of communities and ecosystems.

This strategic phase culminated on October 2, 2015, when India submitted its ambitious Intended Nationally Determined Contribution (INDC). During this phase, climate initiatives (such as solar and efficiency missions and the Perform, Achieve and Trade scheme for industries) were aligned with national development priorities rather than standalone climate mandates.

Phase II (2015–2020): International Alignment.

Following the Paris Agreement (2015), India's climate strategy evolved from a purely domestic "co-benefits" approach to one of active global leadership. While development remained a priority, the narrative shifted towards undertaking bold climate commitments consistent with national circumstances. This phase is defined by India spearheading international institutions—the launch of the International Solar Alliance (ISA) in 2015 and the Coalition for Disaster Resilient Infrastructure (CDRI) in 2019, reflecting a stronger focus on adaptation and resilient infrastructure. Domestically, the action plan expanded beyond the original eight missions of NAPCC; the National Mission on Climate Change and Human Health was operationalised, State Action Plans were aligned with India's NDC, and other high-ambition initiatives were launched.

Overall, this phase demonstrated India's alignment of domestic policy with global commitments, with notable overachievement that projected confidence internationally, while continuing to emphasise disaster-resilient development and protection of vulnerable communities.

Phase III (2021–present):
Net Zero Framing.

This marks the transition from voluntary goal-setting to high-ambition targets. The period began with the announcement of the "Panchamrit" at COP26 in November 2021, including India's commitment to reach Net Zero by 2070, which was subsequently translated into the Updated NDC (2022) mandating a 45% reduction in GDP emission intensity by 2030 and 50% non-fossil fuel power capacity. The Long-Term Low Carbon Development Strategy (LT-LEDS) and the launch of Mission LiFE – Lifestyle for Environment (2022) together broadened India's approach, linking structural low-carbon growth with behavioural change and sustainable consumption.

Unlike previous phases that relied heavily on public funding, Phase III focused on creating self-sustaining market mechanisms and new industrial pathways. The National Green Hydrogen Mission (2023) and the Carbon Credit Trading Scheme (CCTS) became central instruments for transforming hard-to-abate sectors and establishing a domestic carbon market. By 2025, the strategy had shifted from merely "seeking co-benefits" to "decoupling growth from emissions" through deep structural reforms in energy and industry.

Climate is an integral part of India's developmental pathway. Building adaptive capacity across all segments of society and the economy is fundamental to safeguarding livelihoods and growth, even as India mitigates emissions and fulfils its international commitments.

India's policy landscape as of 2025 reflects this balanced approach, where development, resilience and low-carbon transition advance together.

Figure 1.8: Phases of policy evolution

The narrative has thus shifted from viewing climate action only as a co-benefit to recognising it as an important dimension of India's development strategy. India's policy landscape in 2025 is defined by this bold long-term vision of achieving Net Zero emissions by 2070, anchored in nearer-term green growth initiatives and integrated sectoral planning.

1.4.2 Sector-specific Policy Levers

India's climate policy is anchored in sectoral strategies that blend regulatory mandates, market mechanisms, and financial incentives. The Long-Term Low-Emissions Development Strategy (LT-LEDS, 2022) provides the base architecture, identifying long-term options for low-carbon growth while noting the need for iterative policy strengthening as technologies mature and costs decline. In practice, each sector has become a laboratory of policy innovation, where India continues to balance growth and climate goals.

Low-carbon development of electricity systems

The power sector is at the heart of India's emissions pathway. With nearly half of its installed capacity already sourced from non-fossil fuel sources, the country is ahead of its Nationally Determined Contribution (NDC) milestones. This progress reflects a carefully layered mix of mandates, incentives, and infrastructure programs, reinforced by proactive state-level leadership (Figure 1.9).

National frameworks are complemented by ambitious state policies that adapt renewable strategies to local contexts.

NATIONAL LEVEL POLICIES	STATE LEVEL POLICIES
Renewable Consumption Obligations (RCOs) • Mandates DISCOMs, open access consumers, and captive generators to obtain a defined share of their electricity from renewable sources. Targets are specified for each year, with values increasing incrementally through 2030 (43.3%). **Domestic Solar PV Manufacturing (PLI Scheme)** • Total outlay of INR 24,000 crore for high-efficiency modules to set up domestic manufacturing capacity of 65 GW per annum. **Technology-Specific Policies** • National Wind-Solar Hybrid Policy (2018): maximize land/network use • National Offshore Wind Policy (2016): exploration & leasing • PM Surya Ghar (2024): 1 crore homes, 30 GW of rooftop capacity, model solar village • PM-KUSUM (2019): 34.8 GW by 2026; >8 lakh solar pumps • National Programme on Advanced Battery Storage: PLI outlay of INR 18,100 crores, aims to establish a manufacturing capacity of 50 GWh of ACCs and 5 GWh for niche ACC technologies. • Battery Storage Policy: VGF; RE+storage in SECI auctions • SHANTI Act: Emphasizes fuller use of indigenous nuclear resources and active public-private participation, target of 100GW capacity by 2047 **Grid Modernization & Market Enablers** • National Smart Grid Mission (2015): smart meters, DR, digital tools • Green Energy Corridors I & II: RE links across 16 states • RDSS (2021): INR 3.04 lakh crore; AT&C loss — 12–15% • Time-of-Day Tariffs: C&I Apr 2024; Residential Apr 2025 • Power exchanges have introduced various products over last 15 years: TAM, DAM, G-TAM, G-DAM, RTM and the Ancillary Services Market, to increase the liquidity in the spot market. **Co-firing of Biomass Pellets in Coal-based Thermal Power Plants** • For Thermal Power Plants (TPPs), 5% blend (by weight) of biomass pellets.	**Gujarat Renewable Energy Policy (2023)** • INR5 lakh crore across solar, wind, hybrid, offshore, WtE • Surya Gujarat rooftop program expansion **Andhra Pradesh Integrated Clean Energy Policy (2024)** • 160 GW renewables and pumped storage • Focuses on Decarbonisation, Decentralisation, Digitalization and Democratization of power sector **Rajasthan Integrated Clean Energy Policy (2024)** • 125 GW by 2030 (90 GW solar, 25 GW wind/hybrid, 10 GW hydro+storage) • Rajasthan Biomass and Waste to Energy Policy (2023) **Tamil Nadu Wind Repowering Policy (2024)** • Replace old small turbines with modern large ones • Promote hybrid solar–wind facilities **Kerala Decentralized Solar Policy (2025)** • Community-driven clusters and P2P trading • Builds prosumer networks, local resilience **Uttarakhand Policy for Power Generation from Biomass-2018** • 100 MW by 2030 **Uttarakhand Solar Energy Policy 2023** • 2500 MW in the state by December 2027 **Assam Integrated Clean Energy Policy- 2025** • 11,700 MW RE capacity (incl. 1,900 MW rooftop solar). • 3,000 MW solar manufacturing capacity. • 2,000 MW pumped storage + 1,000 MW battery storage. • 2000 kTPA green hydrogen production + hydrogen valley & giga electrolyzer factory. **Uttar Pradesh Solar Energy Policy-2022** • Aims for 22,000 MW solar by 2026-27 (14 GW utility-scale plus rooftop/other solar); focuses on low-cost reliable power and reduced fossil dependence. **Odisha Renewable Energy Policy 2022** • Multi-technology RE policy **Himachal Pradesh Energy Policy, 2021** • 10,000 MW additional "green energy" (hydro, solar, other RE) by 2030 **Jharkhand State Solar Policy, 2022** • 4,000 MW solar by 2027 **Karnataka Renewable Energy Policy 2022-2027** • 10 GW additional RE (including up to 1 GW rooftop solar)

Source: *Government of India, Official Ministry website (detailed references in bibliography)*

Figure 1.9: Power sector policies and initiatives

Low-carbon development of transport systems

Transport contributes about 13% of India's energy-sector emissions. Over the past five years, policy interventions have advanced on four coordinated fronts (Figure 1.10):

i. Tightening vehicle and fuel standards to reduce tailpipe emissions,

ii. Promoting low-carbon fuels and domestic manufacturing to build energy security, and

iii. Investing in public and active mobility infrastructure to shift both people and freight to more efficient modes.

iv. Over 29 states/UTs have implemented EV policies that include incentives, fleet mandates to promote transport electrification.

NATIONAL LEVEL POLICIES

Improving Vehicle & Fuel Standards

- BS VI norms: 25% NOx cut (petrol), 68% (diesel); 82% PM cut for diesel PVs
- Corporate Average Fuel Economy (CAFE) norms: 130 g CO2/km (2017–22), 113 g CO2/km (2022–27).
- Vehicle Scrappage Policy: 60+ RVSFs (17 states/UTs), 75+ ATSs (12 states/UTs); OEM scrappage-linked discounts. Mandates fitness tests for commercial vehicles >15 years and private vehicles >20 years, scrapping failures.

Expanding Low-Carbon Fuels & Domestic Manufacturing

- National Policy on Biofuels: 20% blending by 2025–26.
- SATAT: CBG blending in CGD (1% in 2025–26 → 4% by 2027–28),100+CBG plants operational; 500+ under development
- National Green Hydrogen Mission: INR 496 cr mobility pilots (2025–26) and INR 115 cr shipping pilots
- Sustainable Aviation Fuel (SAF): Mandates 1% SAF blend for international flights from its airports starting 2027.
- Electric mobility push:
  - PM E-DRIVE (2024-28): Outlay of INR 10,900, for 2W/3W, ambulances, trucks and charging stations
  - Battery Swapping Policy: BaaS for 2W/3W
- Mission Electrification by Railways: ~98–99% BG electrified by mid-2025; 100% by 2030

Infrastructural & Modal Shift

- National Rail Plan 2030: freight rail share → 45%; DFCs to shift bulk cargo from road
- Coastal Shipping Bill (2025): Simplified regulation; coastal & inland shipping strategy; incentivise Indian-flag vessels
- Harit Sagar Green Port Guidelines (2023): RE integration, real-time monitoring, annual reporting; top ports recognised
- National Transit-Oriented Development Policy, 2017

STATE LEVEL POLICIES

EV Policies – 29 States/UTs (mid-2025)

- Consumer subsidies, registration/tax waivers(2W/3W/auto/e-car/e-LCV)
- 100% registration fee & road tax waiver (majority of states)
- Fleet electrification mandates (buses, govt fleets)
- Charging ecosystem incentives

Delhi EV Policy

- Already achieved 2,500 electric buses (~33% of fleet)
- Focus on 2W/3W + last-mile freight
- Dense public charging network

Maharashtra EV & Innovation Push

- 467 EV start-ups (June 2025) – highest in India
- 25% bus electrification in 6 urban centres by 2025
- Highway charging every 25 km
- Target: 30% new EV registrations by 2030

Karnataka's Clean Mobility policy (2025-30)

- Electrify all govt. vehicles, corporate fleet and school buses by 2030; create1 lakh jobs

Haryana

- EV Policy (2022) and Haryana Registered Vehicle Scrappage & Recycling Facility Incentive Policy-2024

Tamil Nadu Electric Vehicle Policy (2023)

- Aim to become EV manufacturing hub; 100% e-bus target for 2030

Figure 1.10: Transport sector policies and initiatives

Low-carbon development of industry

Industry accounts for a significant share of India's energy demand and emissions, with steel, cement, chemicals, and MSMEs leading the total consumption. Over the past decade, policy measures have focused on five broad pillars (Figure 1.11):

xi. Energy efficiency and performance benchmarking in energy-intensive industries

xii. Electrification of industrial processes and enabling access to low-carbon electricity

xiii. Adoption of alternative fuels and green hydrogen in hard-to-abate sectors

xiv. Promoting circular economy and resource recovery and

xv. Developing carbon management and trading mechanisms to incentivise emissions reductions.

NATIONAL LEVEL POLICIES

Improving Energy Efficiency (EE) in Industry

- Perform, Achieve and Trade (PAT): Specific Energy Consumption (SEC) targets for energy-intensive industries; tradable ESCerts
- Energy Efficiency Financing Platform (BEE initiative): Accelerates energy efficiency investments by linking financial institutions with industries/MSMEs/project developers.
- MSME cluster programmes: Boosts SME growth, productivity, and competitiveness via firm clustering for shared resources, infrastructure, and capacity building.
- Credit Linked Capital Subsidy and Technology Upgradation Scheme: A 15% capital subsidy with upper cap of INR 15 Lakh→ lower specific energy use

Expanding Low-Carbon & Alternative Fuels

- National Green Hydrogen Mission (2023): Pilots in steel, fertilisers, refining; target 5 MMT GH_2 by 2030; ₹450 cr for steel pilots
- Green Steel Taxonomy (2024–ongoing): star rating for CO2 intensity,3–5 stars, thresholds from <2.2 t $CO_2$to <1.6 tCO_2/t
- GOBARdhan[vi]: Biogas/CBG & organic manure → industrial boilers, cement/textiles
- Waste to Energy (WtE) & Refuse Derived Fuel (RDF) (Solid Waste Management Rules 2016): Support for biomass pellets/bio-CNG

Circular Economy & Resource Recovery

- Steel Scrap Recycling Policy (2019) → EAF/IF route
- CPCB Co-processing (2017) → industrial waste/plastics in cement kilns
- Draft National Resource Efficiency Policy (2019) → reuse/recycling targets
- EPR (plastics → e-waste)
- Non-Ferrous Scrap Recycling Framework (2025–ongoing) → secondary Al/Cu
- BIS IS 18189:2023 (LC3 cement) → ~30% emissions cut
- AMRUT / AMRUT 2.0 / FSSM (ongoing): treated wastewater + sludge-to-biogas linking cities and industrial clusters

Carbon Management & Trading

- Carbon Credit Trading Scheme (CCTS, 2023): compliance carbon market covering 9 sectors
- MISHTI (2024): mangrove-based offsets for coastal/port-proximate industries

STATE LEVEL POLICIES

Gujarat Green Hydrogen Policy (2024–ongoing)

- Capex support + demand aggregation for GH_2 in refineries/steel
- Green Open Access Regulations (2024–ongoing): 100 kW+ industry can procure green power with clearer banking

Maharashtra Integrated & Sustainable Textile Industry Policy (2023–28)

- RE embedded in textile value chain
- Solar capex subsidy up to ₹4.8 crore or 20% (whichever lower), capped at 4 MW per unit

Odisha Renewable Energy Policy (2022): Industrial Linkage

- Scale RE to decarbonise metals, fertiliser, petchem
- Green Hydrogen / Green Ammonia hub vision, leveraging ports + mineral base
- Direct alignment with industrial demand

Other Emerging State Actions

- RE procurement / "single window" cells for MSMEs
- Industrial parks with WtE / common effluent systems
- Early adoption of EPR & circularity for industrial materials

Figure 1.11: Industry sector policies and initiatives

vi GOBARdhan: Galvanizing Organic Bio-Agro Resources Dhan

Promoting Energy and Material-Efficiency in Buildings and Urban Design

The buildings sector—a major and fast-growing source of both operational and embodied emissions—has been identified in the LT-LEDS (2022) as a critical mitigation and adaptation pillar. Policy evolution in this space spans four key fronts (Figure 1.12). Improving energy efficiency; Implementing codes and standards for new construction; Managing cooling demand and; Embedding circularity and waste recovery.

NATIONAL LEVEL POLICIES

Improving Energy Efficiency in Buildings

- Standards & Labelling: Minimum Energy Performance Standards (MEPS) + star labels for 28 appliance/equipment categories; 16 now mandatory; biggest lever for household/commercial savings
- UJALA (2015–ongoing): 370+ million LEDs through bulk procurement & on-bill financing → large drop in residential load
- Building Energy Efficiency Programme: ESCO-style retrofits in public/institutional/industrial buildings (lighting, HVAC, motors) with verified savings
- BEE Star Rating for Buildings: benchmarks actual EPI (>100 kW load) for commercial buildings → transparency + retrofit push
- Shunya Label for Net Zero Buildings (2021–ongoing): recognises Net ero / net-positive buildings with EPI <10 kWh/m²/yr; open to all typologies

Building Codes & Thermal Performance

- ECSBC & ECSBC-R (2024–ongoing): new codes for commercial + large residential; add voluntary embodied-carbon disclosure → 1st national move toward lifecycle carbon in buildings
- ECBC (2007; rev. 2017–ongoing): mandatory for large new commercial buildings (>100 kW); 23 states/UTs notified by 2024
- Together: performance-based + material-carbon lens

Cooling, Refrigerants & Thermal Comfort

- India Cooling Action Plan (ICAP, 2019–ongoing): passive design, high-efficiency equipment, district cooling, phasedown of high-GWP refrigerants; links "thermal comfort for all" to mitigation
- PLI for White Goods (ACs & LED lights): 4–6% incentives on incremental sales → domestic supply chain for efficient cooling & lighting

Circularity

- Solid Waste Management Rules (2016, 2020–ongoing): source segregation, collection, scientific disposal
- Plastic Waste Management Rules (2016, 2021–22–ongoing): EPR, single-use phase-out, recycled plastics for building products
- Swachh Bharat Mission (Urban/Gramin–ongoing): legacy waste remediation + liquid waste management → cleaner urban land banks for construction

Carbon Management & Trading

- Carbon Credit Trading Scheme (CCTS, 2023): compliance carbon market covering 9 sectors
- MISHTI (2024): mangrove-based offsets for coastal/port-proximate industries

STATE LEVEL POLICIES

Green Building Incentives (multiple states)

- FAR/FSI bonus for GRIHA / LEED / IGBC buildings[vii]
- Property tax rebates for certified green buildings
- Reimbursement of certification/ registration fees

State ECBC Notifications / Adoption Drives

- Support to operationalise ECBC / ECBC-R through local bye-laws
- Fast-track building permits for energy-efficient designs

Smart City / AMRUT Convergence

- Public-building retrofits under ESCO model
- District-cooling / common-utility pilots in dense business districts

Figure 1.12: Buildings sector policies and initiatives

vii FAR: Floor Area Ratio; FSI: Foor Space Index; GRIHA: Green Rating for Integrated Habitat Assessment; LEED: Leadership in Energy and Environment Design; IGBC: Indian Green Building Council

Promoting Resource Efficiency and Adaptation in Agriculture

According to the Fourth Biennial Update Report (BUR-4, 2024), agriculture contributed about one-fifth (14%) of India's total GHG emissions in 2020. Within this, methane (CH_4) from enteric fermentation and manure management (~55%), rice cultivation (~17%), and nitrous oxide (N_2O) from fertiliser use in soils (~25%), dominate the profile.

At the same time, agriculture sustains almost 45% of the India's working population, much of which is highly vulnerable to climate variability and water stress. Reflecting these socio-economic realities, agricultural policy has evolved with adaptation as the primary objective, while delivering mitigation co-benefits through productivity improvements, efficient resource use, and climate-smart practices (Figure 1.13).

NATIONAL LEVEL POLICIES

Rice Cultivation & Water Management (CH_4)

- National Food Security Mission (2007): HYVs → ~14% yield rise (2011–19) on ~44 Mha, without adding rice area
- Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) (2015): micro-irrigation, check dams, watershed → enables Alternate Wetting & Drying (AWD) & aerobic rice
- PM-KUSUM: solar irrigation for farmers
  - Comp A: decentralised RE near substations
  - Comp B: standalone solar pumps (diesel replacement)
  - Comp C: solarisation of existing grid pumps + export to grid

Soil Health & Nutrient Management (N_2O)

- Soil Health Card Scheme (2015): 220+ million cards → balanced fertiliser use
- 100% neem-coated urea (2015): better N uptake, checks diversion
- National Mission on Sustainable Agriculture (2014): INM, micro-irrigation, resilient cropping
- Paramparagat Krishi Vikas Yojana (PKVY) (2015): organic farming clusters as low-N alternative

Livestock Productivity & Manure Management (CH_4 & N_2O)

- National Dairy Plan (2012): ~28% higher milk yield (2011–19) → lower emission intensity
- National Livestock Mission (2014): feed, fodder, breed quality
- Rashtriya Gokul Mission (2014): improve/conserve indigenous breeds; shift to high-yielding females
- National Biogas & Manure Management Programme (NBMMP): biogas digesters + composting → cuts manure methane

STATE LEVEL POLICIES

AWD / Aerobic Rice Demonstrations

- Tamil Nadu, Karnataka, Telangana with partners (incl. International Rice Research Institute)
- Goal: lower water use + CH_4 in rice

Organic / Climate-Smart Clusters

- State-level PKVY cells + National Mission for Sustainable Agriculture (NMSA) convergence
- Farmer Producer Organisation (FPO)-led aggregation for organic produce & bio-inputs
- Good for hilly / tribal / rainfed areas

Livestock & Dairy Add-ons

- State Animal Husbandry and Dairying departments supporting breed upgradation & fodder banks
- Co-financing of household / community biogas
- Integrates manure management with village-level CBG pilots

Figure 1.13: Agriculture sector policies and initiatives

2

INTEGRATED MODELLING FRAMEWORK FOR NET ZERO PATHWAYS

Integrated Modelling Framework for Net Zero Pathways

2

India's journey toward Net Zero emissions by 2070 is guided by a comprehensive and integrated modelling framework that combines multiple analytical tools, stakeholder insights, and sector-specific methodologies. This chapter presents the modelling approach adopted to construct India's Net Zero pathways, detailing the suite of models employed and the scenarios designed. It is reiterated here that the underlying philosophy is that of "development first." This exercise seeks to understand how India can achieve its developmental goals while simultaneously contributing to addressing the global challenge of climate change. The pathway outlined is therefore not a "mitigation" or "decarbonisation" trajectory in isolation. Rather, it explores how India can become a developed country in a low-carbon manner, consistent with its national priorities, equity considerations, and the need for sustained economic growth.

The modelling framework begins by identifying the developmental objectives necessary for India to attain developed-nation status by 2047. These include achieving a per-capita income of over USD 18,000, ensuring high living standards, and supporting rapid urbanisation and industrialisation through strong growth in key commodities such as steel and cement. It then examines the developmental choices that can align these goals with long-term sustainability. For instance, meeting a greater share of steel demand through recycled material rather than virgin production can substantially reduce energy use and emissions. These choices, discussed in detail in the *Viksit Bharat* chapter, establish the foundation for a sustainable development trajectory.

Building on this, the modelling framework assesses the least-cost pathways for achieving Net Zero while maintaining the integrity of India's developmental ambitions. The resulting approach is holistic, integrating growth, industrialisation, and environmental objectives to outline pathways that deliver Net Zero outcomes without compromising development goals.

2.1 MODELLING APPROACH AND TOOLS USED

The integrated modelling framework approach is multi-institutional in nature, anchored by a central modelling and coordination group in NITI Aayog. It was supported by ten Inter-Ministerial Working Groups (IMWGs) constituted by NITI Aayog. The framework integrates bottom-up energy system optimisation tools, macroeconomic and econometric tools, and sector-specific Excel-based models into a soft-linked environment, (Figure 2.1). Each tool serves a specialized function and interfaces with others to enable a comprehensive, system-wide assessment of India's long-term low-carbon growth trajectory.

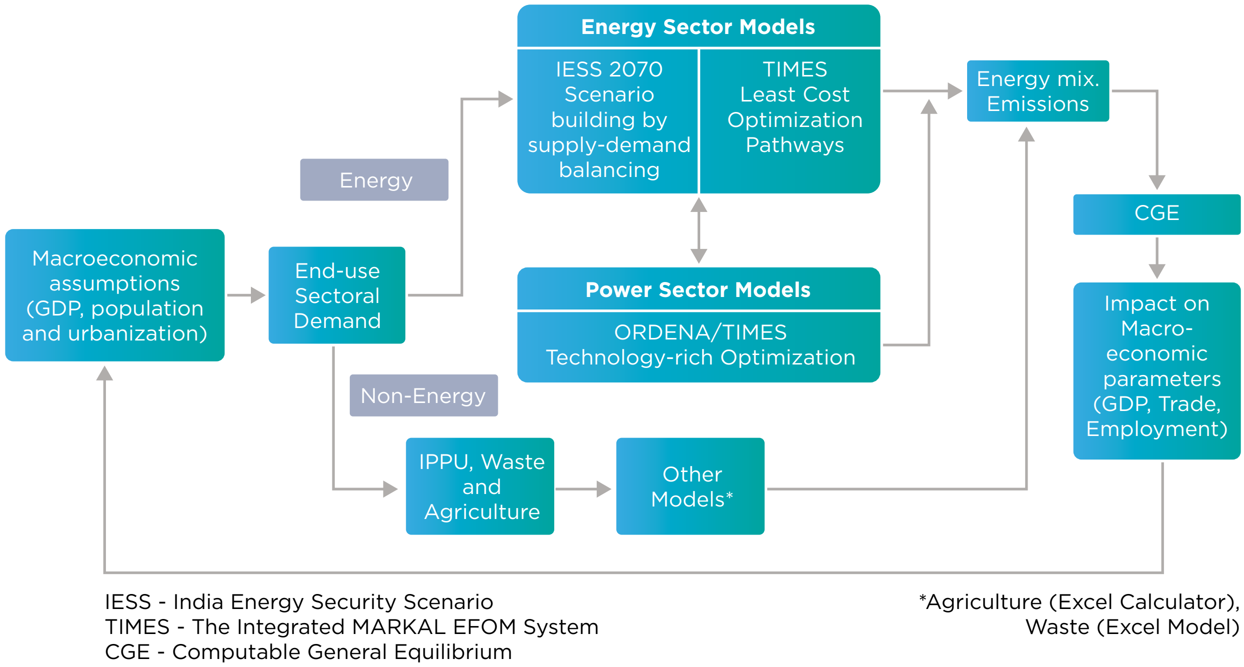


Figure 2.1: Modelling framework for transition pathways

The modelling framework (Figure 2.1) integrates multiple sectoral models into a unified system that links India's development trajectory with its Net Zero pathways. The framework begins with macroeconomic trajectories generated using the Long-Term Growth Model (LTGM), which incorporates the objective of becoming Viksit Bharat by 2047 as well as demographic and sectoral changes envisaged under Viksit Bharat. The macroeconomic inputs, namely GDP, Population, Urbanisation and Sectoral shares, are then fed into Energy and Non-Energy models to estimate future demand. The Energy Sector Models are further disaggregated between end-use sectors, namely transport, buildings, industry, and agriculture, ensuring a granular representation of both demand and efficiency improvements. Energy models first estimate the useful energy, such as demand for commodities (Steel, Cement, etc.) and then use optimisation and scenario tools to generate energy supply outputs. Electricity demand estimated from Energy Models serves as an input to the Power Sector Model, which identifies least-cost pathways consistent with development priorities and emissions targets.

The Non-Energy Sector Models simultaneously evaluate emission reduction opportunities in agriculture, waste, industrial processes, and land use. The outputs from all models are then integrated to synthesise sectoral pathways, technology choices, and mitigation options to deliver an economy-wide trajectory consistent with India's development goals and its commitment to achieve Net Zero emissions by 2070.

The results from the integrated model, especially on energy mix and investment need, are then fed into the Computable General Equilibrium (CGE) Model to assess the macroeconomic implications. This includes estimating the impact on GDP, the structure of GDP, Public finances, Employment and Trade. The subsequent section provides detailed descriptions of each model within the framework.

I. Long-Term Growth Model for GDP Trajectory

The modelling architecture begins with the formulation of a long-term GDP trajectory using the Long-Term Growth Model (LTGM), which is a transparent and widely used macroeconomic tool for projecting long-run GDP per capita growth and its implications for poverty reduction. Based on an enhanced Solow-Swan[viii] framework, it incorporates country-specific factors such as human capital, demographics, investment, and total factor productivity. Used in over 50 countries, the LTGM supports analysis of structural reforms, debt sustainability, and long-term development. This modelling exercise enables consistent projections of India's potential growth and ensures alignment with sectoral models.

A reference macroeconomic growth trajectory, aligned with the Government of India's Viksit Bharat 2047 vision, is adopted to ensure consistency in underlying assumptions across all models. This projection is based on assumptions related to capital formation, labour force expansion, productivity improvements, and structural transformation of the economy (discussed in Viksit Bharat). The resulting GDP trajectory informs downstream estimates of energy demand, emissions, and technology transitions, forming a robust foundation for simulating India's Net Zero pathways.

II. Energy Models for Energy and Emissions Trajectory

India's economic structure comprises a range of critical sectors, such as transport, buildings, industry, agriculture, and services, that are central to long-term growth and development. These sectors not only drive economic output but also represent the primary sources of energy demand. Their expansion is intrinsically linked to macroeconomic trends, including GDP growth, population increase, urbanisation, and structural transformation.

To accurately project future energy requirements, each sector is modelled individually using tailored methodologies and activity indicators relevant to its operations. These sectoral demand models, discussed in detail in the subsequent chapter, collectively determine the final energy demand of the economy. On the supply side, energy sources are modelled to meet this demand in the most cost-effective and technologically feasible manner, while adhering to India's commitment to achieve Net Zero greenhouse gas emissions by 2070.

To undertake this integrated demand and supply modelling (as shown in Figure 2.2), two complementary tools developed in-house by NITI Aayog were used, with major stakeholders providing inputs and feedback to inform the modelling assumptions and datasets. These include:

i. ***TIMES (The Integrated MARKAL-EFOM System)*:** TIMES is an optimisation-based bottom-up energy system model that identifies the least-cost pathways to meet projected energy-service demands under given resource constraints and policy goals. It evaluates a broad range of technology and fuel options to determine how India's energy system can evolve. TIMES is particularly suited for long-term scenario planning, supporting the comparison of alternative pathways such as the Current Policy Scenario (CPS) and the Net Zero Scenario (NZS).

ii. ***IESS (India Energy Security Scenarios)***: IESS is a policy-simulation tool developed by NITI Aayog. It enables users to explore how various policy choices and technology

viii Solow-Swan framework: A neoclassical growth model in which long-term growth is driven by technological progress rather than merely by more capital or labour.

pathways could influence India's energy system over time. IESS is designed for transparency and user interaction, allowing real-time assessment of how policy shifts affect energy demand, supply, emissions, and sectoral performance. It is particularly useful for testing potential impacts of future policy interventions.

Both TIMES and IESS models are harmonised to ensure internal consistency and are used jointly to construct the Current Policy Scenario (CPS) and the Net Zero Scenario (NZS) for this modelling exercise.

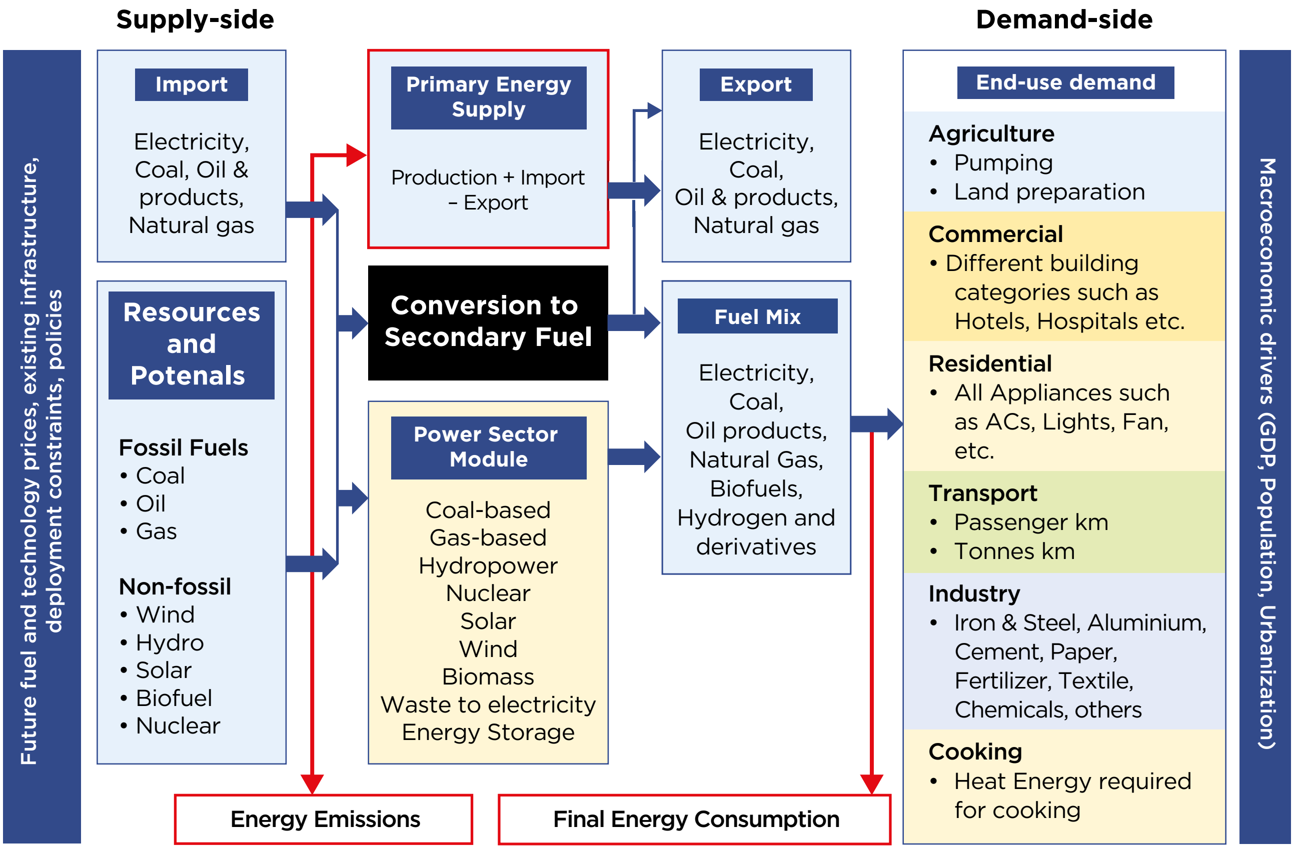


Figure 2.2: Energy model structure (demand-supply balance)

iii. ***Power Sector Models:*** Detailed power sector models have been developed by NITI Aayog (TIMES Power Model) and the Central Electricity Authority (ORDENA) to project future capacity expansion, generation mix, and the requirement for flexibility resources such as energy storage systems. The aggregate electricity demand estimated from the integrated energy models for each sector is provided as input to these detailed power-sector models.

These models are technology-rich, containing unit-level information on thermal power plants, and feature a high temporal resolution of 288 time slices to capture hourly and seasonal variations in load and renewable energy generation. Modelling on these platforms is carried out using consistent electricity demand assumptions, and the results are harmonised to ensure alignment in both capacity expansion and generation mix outcomes.

III. CGE model for Macroeconomic Implications

To assess the broader economic implications of India's energy transition, a Computable General Equilibrium (CGE) model, developed jointly by NITI Aayog, the World Bank, and National Council of Applied Economic Research (NCAER), is employed. The model evaluates economy-wide impacts such as changes in GDP, sectoral output, employment, household welfare, and trade balances.

The outputs of the energy system model are fed into the CGE framework to assess the implications of the Net Zero pathway on key macroeconomic indicators, including fiscal deficit, current account deficit, public debt, fossil fuel tax revenues, and the fuel import bill. This model is explained in detail in the report on Macroeconomic Implications of Energy Transition (Volume 2).

IV. Non- Energy Models for Agriculture and Waste

To capture emissions beyond the energy sector, dedicated Excel-based models were developed to estimate non-energy Greenhouse Gas (GHG) emissions, particularly from the agriculture and waste sectors. These models, developed in partnership with Council on Energy, Environment and Water (CEEW) and ICLEI-Local Governments for Sustainability South Asia, respectively, use sector-specific methodologies consistent with IPCC inventory guidelines and are calibrated to India's Biennial Update Report (BUR) data.

The agriculture model covers emissions from enteric fermentation, rice cultivation, manure management, soil management, and agricultural residue burning, while the waste model estimates emissions from municipal solid waste and wastewater (industrial and domestic). The resulting estimates are integrated into the overall GHG trajectory to ensure completeness and consistency across sectors.

Other Tools Used for Complementary Analysis: In addition to the core modelling frameworks, sector-specific Excel-based tools were developed to support targeted analyses essential for Net Zero planning. These included models to estimate finance requirements and critical mineral demand for technologies such as batteries and solar photovoltaics (PV) systems. Together, these tools provided granular, decision-relevant insights to inform investment strategies, technology prioritisation, and policy design.

2.2 DESIGNING INDIA'S PATHWAY TO NET ZERO EMISSIONS

There is no single approach to achieving Net Zero emissions. External shocks are inevitable, economic conditions and energy prices will fluctuate, and policies and technologies may perform better or worse than anticipated. While many affordable clean energy technologies can already be implemented with supportive policies, India's transition will also depend on how successfully emerging low-emission technologies such as carbon capture, green hydrogen, and advanced energy-storage systems are demonstrated, commercialised, and scaled globally.

International market developments and renewable energy trends will also influence India's energy security and low-carbon growth trajectory, given that it is one of the world's largest energy consumers and importers of fossil fuels.

India's Net Zero journey must reflect its national circumstances: relatively low per capita energy consumption (about one-third of the global average), a high use of coal in electricity generation, regional disparities in economic and energy development, and the imperative to lift millions out of energy poverty.

India's vast renewable energy potential, especially solar, wind, small hydro, and bioenergy, offers major opportunities for large-scale clean energy expansion. However, this must be achieved while ensuring affordability, reliability, and inclusive growth. The objective of this analysis is not to prescribe a single definitive route to Net Zero, but to present a feasible and adaptive pathway that is:

i. Anchored in India's developmental needs and energy sector realities across states and regions.

ii. Aligned with global market shifts and technology evolution.

iii. Flexible enough to accommodate uncertainties in energy demand growth, investment flows, and sectoral transitions.

What follows is a scenario-based outline of how India could achieve economy-wide Net Zero emissions by 2070, consistent with the country's Long-Term Low Emissions Development Strategy (LT-LEDS). It presents key modelling assumptions, sectoral emissions trajectories, and transition dynamics across energy supply and end-use sectors, with a focus on balancing low-carbon growth, and equity.

Base year

The analysis adopts 2023 as the base year, with all available empirical data calibrated and validated against this reference year. Forward-looking projections are undertaken for the period post-2023 through 2070, with the modelling horizon commencing in 2025 and results captured at five-year intervals. As data availability varies across sectors, in sectors such as industry and buildings, comprehensive datasets for 2023 are not consistently available; 2020 is used as a reference year for presenting historical data to ensure consistency of results across all sectors and alignment with reported emissions.

The first projection year is 2025, and accordingly, model outputs are presented from 2025 onward. Results for 2050 are included to assess progress toward development goals and 2070 results represent the long-term Net Zero outcome. In sectors where more recent empirical data are available, such as the power sector, observed data for 2025 are also presented to enable direct comparison between actual outcomes and modelled trajectories.

Scenario Design:

The study examines India's transition through two principal scenarios: the Current Policy Scenario (CPS) and the Net Zero Scenario (NZS).

i. **Current Policy Scenario (CPS)**: The Current Policy Scenario represents a level of effort that is realistically achievable based on historical trends and continuation of current policies (as of 2023), thereby projecting ongoing trends in low-carbon technology deployment.

ii. **Net Zero scenario (NZS):** The NZ scenario reflects an ambitious pathway aligned with India's commitment to achieve Net Zero GHG emissions by 2070. It incorporates both existing and additional policy measures to accelerate demand electrification, enhance circularity, improve energy efficiency, promote the rapid development of low-carbon technologies/fuels and encourage behavioural shifts.

Each energy and non-energy sector-transport, buildings, power, industry, agriculture, and waste-is modelled using sector-specific methodologies designed to accurately project activity levels, consumption patterns, and emissions. Detailed descriptions of these methodologies are provided in the respective subsections of the following chapter, while comprehensive assumptions and modelling approaches are documented in the full Sectoral Working Group reports. All model results are calibrated to 2020 and 2022 data, with 2025 as the first projection year, and are further refined wherever updated data from Ministry reports are available, such as for the electricity sector. Accordingly, results are presented for both 2020 and 2025.

Limitations of the Analysis

The results presented in this report are derived from a scenario-based economy-wide energy climate modelling framework. As with all long-term system models, the findings are subject to underlying assumptions and methodological constraints. This section briefly summarises the key limitations of the analysis and clarifies how these should be considered when interpreting the results.

i. **Deterministic Modelling Approach:** The current analysis is deterministic and relies on a transparently defined set of assumptions on GDP growth, fuel prices, technology costs and fuel prices. While these assumptions are grounded in the best available evidence at the time of analysis, actual future outcomes may diverge from these estimates.

   Accordingly, the results should be interpreted as two plausible scenarios or estimates of the future, rather than predictions. The findings are indicative and contingent on specific modelling choices, rather than definitive or exhaustive. However, given the comprehensive stakeholder consultation with line ministries, various think tanks, research bodies and academia, there is high confidence in the directionality and insights indicated. Readers should not focus on specific numbers but rather the trends for future directions.

ii. **Uncertainty from breakthrough technological change:** The model is built based on currently available technologies and a set of emerging technologies that are already at an identifiable stage of development, demonstration and early deployment. Completely new breakthrough technologies or paradigm-shifting innovations that may emerge over the long term are not represented, which means future pathways could diverge significantly if such technologies materialise at scale.

iii. **Bi-directional linkage of energy–economy:** The framework applies a single, one-way coupling approach. A long-term growth model generates GDP projections, from which activity levels and energy demand in end-use sectors are derived, and the macroeconomic and social implications of the resulting energy and investment pathways are then assessed. While these macroeconomic outcomes may influence GDP and the structure of the economy, an iterative coupling process where revised GDP is used again to estimate energy demand and the least-cost supply mix, was not undertaken in this analysis. Instead, the baseline GDP structure was retained to maintain consistency across modelling steps, with the understanding that such iterative refinement could be explored in future work.

iv. **Linkage of land, water, and energy:** Land and water requirements of energy transition are estimated ex-post for the chosen pathways, rather than emerging endogenously from a fully coupled Climate-Land-Energy-Water (CLEW) optimisation framework.

v. As a result, there is no explicit feedback loop in which land and water availability, competition with other uses, or related environmental constraints reshape energy pathways. Thus, key trade-offs, co-benefits, and system-wide co-optimisation across these domains remain only partially explored.

vi. **Spatial Granularity:** The analysis provides a coherent national-level pathway that can guide the overall direction of state strategies, but it does not capture state-specific fuel and resource endowments, policy settings, or demand patterns. Consequently, detailed state-level planning will need separate, higher-resolution assessments that reflect local economic structure, infrastructure constraints, and climate and weather conditions.

vii. **Infrastructure requirement:** The modelling exercise does not endogenously represent infrastructure build-out, such as transmission and distribution grid expansion or supporting road-rail logistics; instead, grid investment needs are estimated exogenously using simplified cost assumptions. This can understate spatial and timing constraints, overlook bottlenecks that affect technology deployment and system reliability. This may misrepresent the macro-economic effects of large-scale infrastructure programmes, including employment, regional development and crowding-in of private investments.

viii. **Impact of cross-border trade and international carbon policies:** The model does not represent the dynamics of international commodity trade such as Carbon Border Adjustment Mechanism (CBAM)-like policies, Free Trade Agreement (FTA) negotiations, etc. As a result, risks to export volumes, terms of trade, and sectoral restructuring pressure arising from carbon-constrained and geopolitically volatile markets are not quantified within the modelling framework.

Future Enhancements

Future enhancements to this study could focus on systematically addressing these limitations by: incorporating explicit uncertainty analysis around key drivers (GDP, technology costs, fuel prices) and using integrated modelling of multiple model types for strengthening bi-directional energy-economy linkage through iterative coupling with macro-economic models; and progressively moving towards integrated CLEW-type formulations where land and water constraints feed back into or co-optimised with energy choices.

This study in future can expand the technology database and scenario design to explore disruptive and breakthrough options. Further, higher spatial and temporal resolution in the power sector, endogenous representation of infrastructure expansion, and explicit modelling of cross-border commodity and energy trade under alternative carbon policy regimes would help capture regional heterogeneity, operational constraints and trade-related transition risks more robustly.

Overall, this analysis is intended as a living document, to be periodically revisited and refined as new data, policies, and technologies emerge. Continuous improvement of the modelling framework will support more adaptive, resilient, and realistic planning as India advances towards its Net Zero objectives.

3

FRAMING INDIA'S CENTURY—THE VIKSIT BHARAT VISION & SUSTAINABLE PATHWAYS

Framing India's Century—The Viksit Bharat Vision & Sustainable Pathways

3

Viksit Bharat is a forward-looking vision laid down by the Hon'ble Prime Minister for India's transformation into a developed nation by 2047 and become a USD 30 Trillion economy. Beyond economic targets, it envisages a future India based on inclusive growth, improved living standards, a competitive economy, robust infrastructure, and technology and innovation leadership. It also targets progress across social indicators such as life expectancy, education, and skills. This journey is not just about expanding output; it marks a fundamental transformation in how India produces, consumes, and grows. This shift will profoundly reshape key sectors, including urban development, transport, industry, and buildings.

3.1 HARNESSING INDIA'S STRATEGIC ENDOWMENTS

1. Demographic Dividend

With a population exceeding 1.4 billion and a median age of 28, India remains one of the youngest nations, a demographic trend expected to last until the mid-2050s (Ministry of Finance, 2025). This provides a significant edge in becoming the global supplier of human capital. With more than 2 million Science, Technology, Engineering and Mathematics (STEM) graduates annually, and the third-largest startup ecosystem[ix], India is well-positioned to lead the global digital and innovation workforce.

2. Future-ready digital infrastructure

In 2009 only 17% of Indian adults had a bank account and 15% accessed digital payments. Today, India has over 1 billion Aadhaar-linked identities; tele-density exceeds 90%; and, more than 6 billion monthly digital transactions take place through the Unified Payment Interface (UPI). A Bureau of Indian Standards (BIS) study notes that India achieved in one decade the level of financial inclusion that took many other economies nearly 50 years. Initiatives such as COVID Vaccine Intelligence Network (Co-WIN), DigiLocker – digital document storage platform (DigiLocker), Open Network for Digital Commerce (ONDC), and Open Credit Enablement Network (OCEN) exemplify India's Digital Public Infrastructure (DPI) leadership (Ministry of Finance, 2025).

3. Technology-Driven Governance

Reforms in tax administration (for example, the GSTN and faceless assessments), business facilitation (including single-window clearance and the UMANG app), and real-time public

ix https://www.pib.gov.in/PressReleasePage.aspx?PRID=2085956 service delivery have created a transparent, digital-first, and citizen-centric governance model. These measures have significantly improved the ease of doing business and enhanced efficiency in public resource use (Economic Survey, 204-25).

4. Strong and Empowered Private Sector

Since 2014, the government has recognized and encouraged private sector dynamism. Reforms such as the disinvestment of Air India, the Insolvency and Bankruptcy Code (IBC), decriminalization of business laws, asset monetisation, and reduction in tax rates have strengthened investor sentiment and entrepreneurial confidence. The Production Linked Incentive (PLI) schemes aim to develop global leaders in sectors such as electronics, pharmaceuticals, automobiles, textiles, and green technologies (Economic Survey, 2024-25).

5. Rich Renewable Energy Potential

India is richly endowed with renewable energy resources particularly solar and wind. This clean-energy foundation strengthens energy sovereignty and can support India's industrial transition, clean mobility future, and climate leadership.

6. Global Indian Diaspora

India's diaspora of over 30 million people, the world's largest, serves as a bridge to global finance, innovation ecosystems, and soft power. Leveraging this diaspora for knowledge transfer, capital flows, and diplomatic engagement will be critical in the journey toward Viksit Bharat.

Together, these endowments create the capacity in talent, technology, governance, and investment appetite on which the Viksit Bharat strategy is built. The narrative recognizes India's structural strengths, its demographic advantage, digital infrastructure, entrepreneurial energy, and renewable energy potential. It also acknowledges the challenges ahead: rapid urbanisation, resource constraints, climate risks, and the need for large investments in infrastructure and human capital.

By anchoring the analysis in the *Viksit Bharat* vision, this report sets the for a policy framework that is both ambitious and grounded in India's realities. The vision serves as the unifying context for all subsequent analysis and policy recommendations, ensuring that every pathway and action aligns with India's long-term development goals. With the vision and endowments now defined, the next step is to translate *Viksit Bharat* into actionable policy pathways that turn capacity into outcomes.

3.2 FROM ASPIRATION TO ACTION- TRANSLATING THE VIKSIT BHARAT VISION INTO POLICY PATHWAYS

To graduate into the ranks of high-income nations by 2047, India must sustain real GDP growth of over 7% per year for over 20 years, a goal that is achievable through targeted reforms that enhance productivity and inclusivity.

1. From Labour Surplus to a Productivity Powerhouse

A central challenge for India is to convert its demographic advantage into a workforce advantage. Today, only 5–7% of the working-age population has received formal skills training. For a Viksit

Bharat, this share must converge with global peers like South Korea or Germany, where over 70% of the workforce receives structured vocational training.

A developed India will be one where all citizens participate meaningfully in the economy. Increasing labour force participation, especially among women, is essential not only as a matter of equity but also as a growth imperative. Raising female labour-force participation to the levels seen in high-income economies (about 70%) would enhance productivity, household income, and consumption. Expanding formal employment, vocational training, and reskilling programmes for youth and mid-career workers will help maintain a globally competitive workforce. India's aspiration to lead in skilled manpower must be matched by universal access to skill infrastructure, industry-aligned curricula, and pathways for upward mobility.

2. Manufacturing-led Structural Transformation

India's economic structure remains skewed toward low-productivity agriculture. The path to Viksit Bharat necessarily involves industrial deepening, particularly in manufacturing. By boosting the share of manufacturing in GDP, India can absorb surplus rural labour, diversify exports, and move up the global value chain.

Recent policy efforts, including the Production Linked Incentive (PLI) schemes and the National Manufacturing Mission, aim to make India a competitive manufacturing base in sectors such as electronics, semiconductors, pharmaceuticals, automotives, and textiles. Technological advancement will accelerate total factor productivity (TFP), driven by greater adoption of clean energy and digital innovation.

3. Integrated Urban Growth and Infrastructure

India's cities will be the fulcrum of future economic growth. By 2047, India could see many urban agglomerations with GDPs exceeding USD 50 billion each. These cities must be supported by robust public services, multimodal transport, and sustainable infrastructure. Innovations in housing, sanitation, waste management, and mobility combined with greater governance reform in urban local bodies will improve the quality of life for most of India's population.

4. Improving and Expanding Healthcare

A Viksit Bharat must also be a healthy Bharat. By 2047, India envisions a society where healthcare is accessible, affordable, and preventive. Achieving this requires a full-spectrum transformation: from reducing maternal and infant mortality to strengthening primary healthcare, and reforming health financing and workforce systems.

India will need to converge with global health benchmarks on indicators such as life expectancy, infant mortality rate (IMR) and under-five mortality, matching levels seen in OECD countries. Reducing out-of-pocket expenditure (OOPE) to below 20%, in line with global norms, will be essential.

India must also focus on non-communicable diseases through lifestyle changes and expand elderly-care facilities to address the demographic transitions in a Viksit Bharat.

5. Education Systems for the Future

A developed India cannot happen without an educated India. The road to 2047 envisions a system in which every child enters school, stays in school, and thrives in school. The universalisation of school education from foundational to secondary levels must ensure 100% enrolment and retention supported by gender equity, National Education Policy (NEP) aligned pedagogy, and digitally connected classrooms.

Beyond school, India must expand higher education. The NEP 2020 targets a gross enrolment ratio (GER) of 50% by 2035, consistent with developed country benchmarks. Strengthening research, innovation, and entrepreneurship ecosystems within universities will transform youth from job seekers to job creators.

Enrolment in vocational education such as ITIs, polytechnics, and short-cycle programmes must also expand, offering diverse and industry-aligned pathways promoting employability. Reducing dropout rates at secondary and higher-secondary levels will ensure smoother transitions to productive employment.

Literacy must become foundational, not just formal, extending to digital literacy, financial literacy, and employability skills for all age groups. Driven by such investments, India's Human Capital Index (HCI) is expected to converge with global benchmarks.

6. Global Value Chain Expansion and Export Diversification

A Viksit Bharat will be embedded in global markets not just as a supplier of raw materials or services, but as a key node in sophisticated value chains. India must expand its share of intermediate goods exports, especially in pharmaceuticals, chemicals, electronics, and textiles, through logistics improvements, trade facilitation, and R&D support.

Developing integrated manufacturing hubs, negotiating free-trade agreements (FTAs), and offering targeted incentives can position India as a global production and innovation hub.

7. Inclusive and Just Growth

Per capita GDP alone will not define India's development. Viksit Bharat will be a Bharat where poverty, especially multidimensional poverty is virtually eradicated; where no child goes hungry; and every household has access to clean cooking, safe drinking water, electricity, internet, and modern housing.

8. Green Growth and Climate leadership

In the Union Budget 2023, the Government of India formally identified "Green Growth" as one of the seven Saptarishi priorities for Amrit Kaal, signalling its centrality to India's long-term development strategy. The other priorities include – Inclusive Development, Reaching the Last Mile, Infrastructure and Investment, Unleashing the Potential, Youth Power and Financial Sector. The green growth agenda is not limited to emissions reduction; it aims to enable inclusive and equitable economic transformation. This includes solarisation of agriculture, helping MSMEs adopt low-carbon technologies, and creating green jobs in construction, mobility, and waste management. The government's approach seeks to ensure that the benefits of the transition are widely shared, while vulnerable sectors and communities are supported as they shift away from fossil-intensive pathways

India's commitment to sustainability is deeply embedded in a civilisational ethos of living in harmony with nature, reflected in traditional practices and Vedic philosophy that treat the environment as a shared inheritance rather than a resource to be extracted. This cultural foundation has been reinterpreted in contemporary terms through the Prime Minister's Mission LiFE (Lifestyle for Environment), which promotes responsible consumption and environmentally conscious behaviour. Launched by the Prime Minister at COP26, LiFE has since gained global traction, including endorsements from the United Nations and the World Bank, as a scalable and citizen-driven model for sustainability.

On the global stage, India has emerged as a strong advocate for climate equity, calling for enhanced climate finance, a fair allocation of the remaining carbon budget, and recognition of common but differentiated responsibilities (CBDR). Initiatives such as the International Solar Alliance (ISA), the Coalition for Disaster Resilient Infrastructure (CDRI), and Mission LiFE reinforce India's leadership in shaping cooperative, sustainable, and resilient global development.

By translating the Viksit Bharat vision into actionable policy pathways, India can ensure that its journey to developed-nation status is both inclusive and sustainable, with each reform reinforcing long-term national goals. These policy levers operate within demographic and urbanisation trajectories. The projections in the next section set the scale and timing of needs.

3.3 MACROECONOMIC BLUEPRINT: DEMOGRAPHY AND ECONOMIC TRANSFORMATION

The transition from aspiration to action requires translating broad policy principles into quantitative frameworks grounded in India's demographic and economic realities. This section therefore presents foundational drivers that define India's development envelope: population evolution, accelerating urbanisation, and macroeconomic growth. These projections establish the scale of demand for housing, mobility, industrial goods, and energy services, the quantities on which sectoral and energy strategies must build.

3.3.1 Demography: Population and Urbanisation

Demographic and urbanisation paths form the quantitative backdrop against which demand, services, and infrastructure must scale. The results below directly inform macroeconomic design and sectoral pathways.

iii. **Population:** India's population is projected to peak at 1.62 billion by the mid-2060s before stabilising and gradually declining to around 1.6 billion by 2070. The working-age population continues to grow until 2044, giving India a demographic window of opportunity to boost industrialisation, services, and green employment.

iv. **Urbanisation:** India's urban population is projected to grow from 37% in 2023 to 65% by 2070, reshaping the built environment and infrastructure demands. The shift presents a historic opportunity to construct modern, sustainable, and inclusive cities.

3.3.2 Macroeconomic Growth Trajectory

India's Net Zero pathway is a development–first transition, sustaining high growth, rapid urban transformation, and industrial upgrading while decisively pursuing low-carbon options.

High-investment Growth Through 2047

The growth path is investment-led, with real GDP growth averaging 7.0% through 2047, lifting the economy to USD 30 trillion and per-capita GDP to more than USD 18,000. This trajectory rests on sustaining an investment rate near 34% of GDP through 2047, increase in female labour-force participation towards high-income country benchmarks (about 70%), and human-capital convergence towards developed-economy levels. Total factor productivity (TFP) growth is assumed at 2.18% per year to 2035 (versus about 1.88% in 2010–2019), moderating to 1.88% by 2047.

Financing Design is Pivotal

The run-up to 2047 is necessarily investment-heavy with grids, renewables, industrialisation, and urbanisation dominating demand. Domestic borrowing-heavy pathways tend to raise real rates and crowd out private capital expenditure and consumption, whereas blended or external capital eases rate pressures, sustains investment, and keeps household demand more resilient.

Historical Analogues and India's Starting Point

Long spells of high growth anchored in elevated investment, urbanisation, and labour reallocation, observed in peers such as China and Indonesia, typically moderate as economies mature. India's large farm-to-non-farm productivity gaps and a still-rising working-age population provide room for a similar investment-led catch-up through the 2030s–2040s, before a gradual transition toward efficiency- and scale-driven growth.

Post-2047 trajectory. As TFP growth slows towards 0.9% by 2070, consistent with advanced-economy convergence and the Human Capital Index (HCI) stabilises around ~0.6, real GDP growth tapers to about 2–3% by 2065–70 (see Figure 3.1)

Structural Transformation

The structure of GDP and GVA also shifts. Agriculture's share in GVA (14.4% in 2024-25) is expected to decline to around 10% by 2070 as productivity rises and the workforce moves into non-farm sectors. Industry share increases from 30.7% in 2024-25 to 33.6% and thereafter reduces marginally by 2070, a trend seen in other developed economies. While the share of services, the largest source of value-add rise from 54.9% to more than 59% of GVA by 2070. This pattern is typical of a maturing economy and signals movement toward higher-value activities and a more urban, service-oriented society.

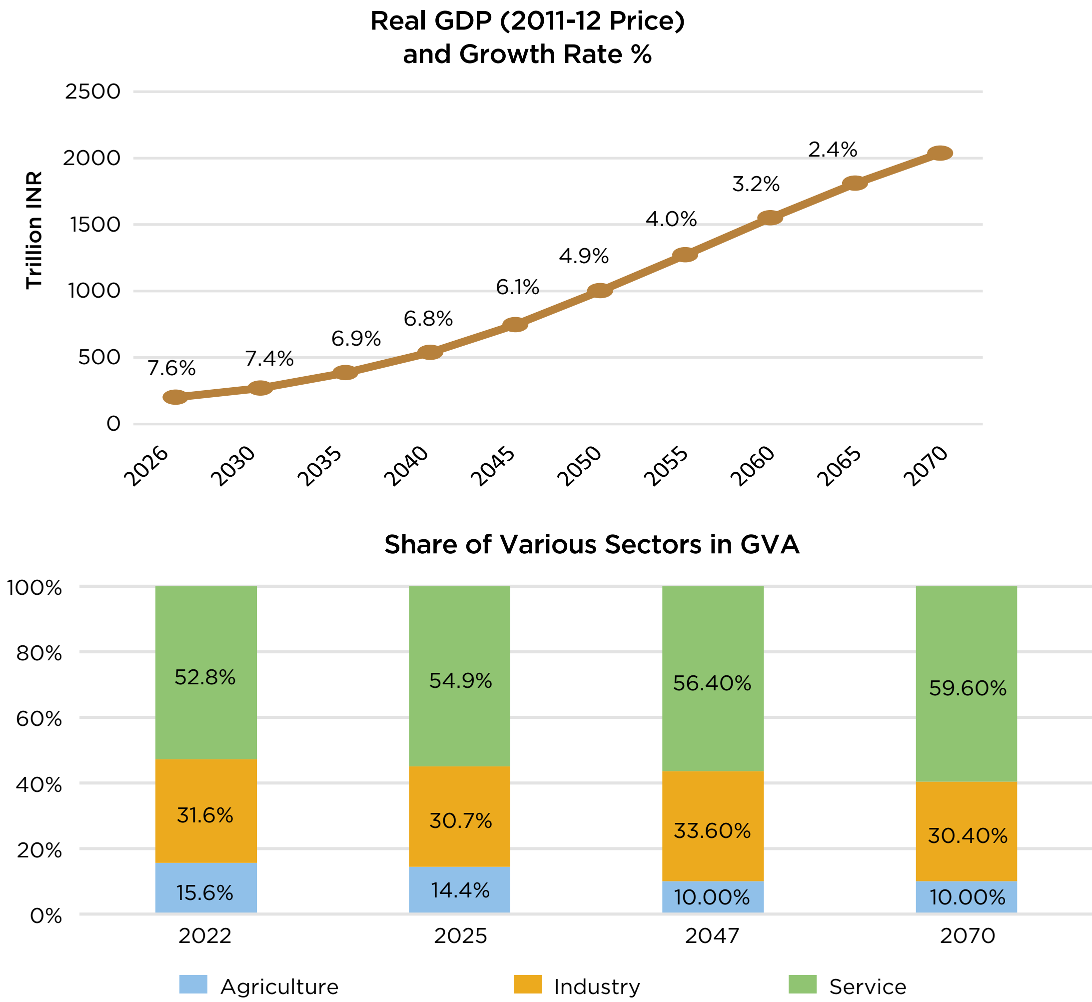


Figure 3.1: Real GDP from 2026 till 2070 (estimated using long term growth model tool) (up), structure of gdp (down)

Cross-country Evidence

Labour reallocation and productivity gains go hand-in-hand. In China, agriculture's employment share fell from roughly 45% in 2005 to about 22% in 2023 as services and industry expanded. Indonesia shows a similar arc, with the share of agriculture in employment declining from 44% in 2005 to about 29% in 2023, and services nearing 49% of employment. These comparators illustrate the growth dividend from shifting workers into higher-productivity activities.

The declining reliance on agriculture underscores the need to raise farm productivity and rural incomes even as urban-centric services and industry led grow. A larger services share also implies lower energy intensity, supporting low-carbon transition.

3.4 SECTORAL DEVELOPMENTAL CHOICES AND DEMAND DRIVERS

Rising incomes and urbanisation accelerate demand for housing, mobility, industrial goods, and public services. This section presents quantitative projections across buildings, transport, and industry, their implications for energy use and emissions, and the strategic levers required to ensure sustainability, resilience, and efficiency.

Floor Space Expansion

India's urban population is projected to rise from 37% in 2023 to 65% by 2070, reshaping the built environment and infrastructure demands. By 2047, the urban share of population is expected to reach 51%, translating to 814 million urban residents (vs 471 million in 2020). This rural-to-urban migration multiplies demand for buildings, appliances, transport, logistics, and urban services, altering energy and resource use. With so much yet to be constructed, India has a rare window to build sustainably. The choices made now will shape not only how fast India grows, but how well it lives.

The total floor space needed rises by around 2.5 times, from 18 billion m^2 (2020) to 42 billion m^2 by 2070. The overall building stock needs to double by 2050 and 2.5 times by 2070 (Figure 3.2). Accounting for demolitions, 86% of the 2070 building stock is yet to be built. This creates a once-in-a-century opportunity to embed resource efficiency and energy optimisation from the outset. The largest increase is in residential floor area, driven by homeownership aspirations, rising incomes, and urban migration. Per-capita floorspace needs double from 12 m^2/person (2020) to 23 m^2 by 2070. Under constraints of rising population density and limited land, India's growth will rely more on vertical housing and efficient urban planning. This is similar to Singapore's experience. Even by 2070, India will remain below China (~36 m^2) and the USA (~60 m^2) on per-capita floorspace, signalling efficient land use.

Services-led growth and rising consumer spending will lead to a significant increase in the commercial building segment. This needs to more than triple from ~1.3 billion m^2 in 2020 to ~4.4 billion m^2 by 2070, raising its share of total stock from ~7% to ~10% (See Figure 3.2). This is because of increase in office space, retail, hospitality, health and education facilities, transit hubs, and warehousing, reinforced by initiatives such as industrial corridors and the digital economy (e-commerce, data centres, GCCs).

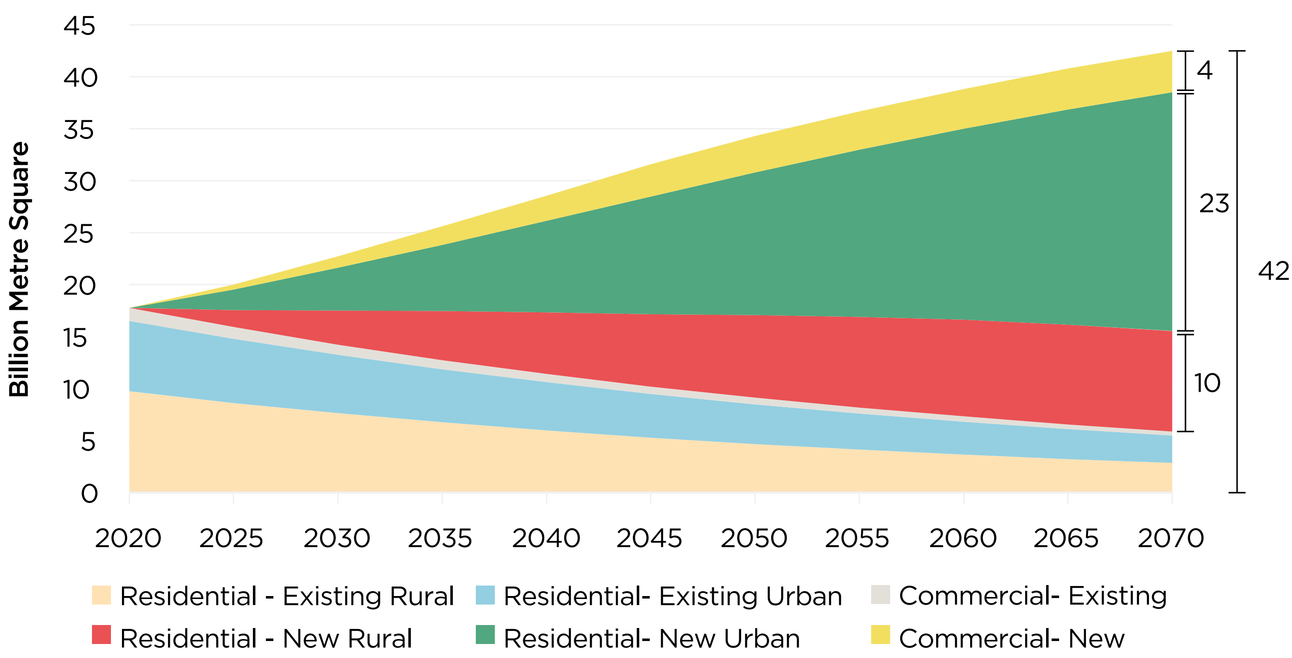


Figure 3.2: Floor Space Projections for residential and commercial buildings (2020-2070)

Appliance Penetration-from Latent Demand to Mass Adoption

India exhibits exceptionally high latent cooling demand, yet it has among the lowest access to air conditioning. Latent cooling demand is measured through person cooling degree days[x]. Figure 3.3 shows that India has a very high level of heat stress (>> 4.0 trillion person-Cooling Degree Days) but among the lowest AC ownership (~8% of households). By comparison, countries like China and Korea combine high cooling demand with 60–80% AC ownership.

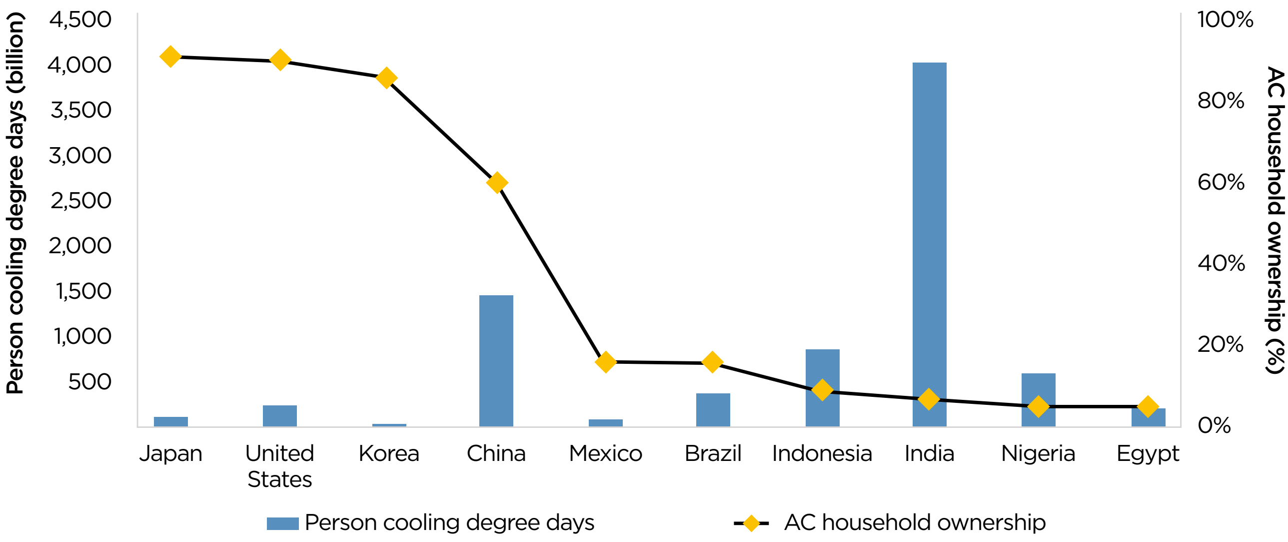


Figure 3.3: Person cooling degree days vs ownership of air conditioners for select countries

Recent data from the Bureau of Energy Efficiency (BEE) impact assessment report 2022-23 shows that room-AC (RAC) production grew 24% per annum (2018-19 to 2022-23). Looking ahead, projections indicate a rapid rise in cooling demand. The India Cooling Action Plan estimates that RAC ownership could reach around 40% by 2037–38. This is further projected to reach 80% in urban areas and around 50% in rural areas by 2047, and 80% by 2070 (mass adoption by mid-century, broad saturation thereafter). According to the IEA's World Energy Outlook, (2023) residential air-conditioner ownership is projected to grow ninefold by mid-century.

Rising incomes and aspirations will drive increases in demand for other appliances as well, such as refrigerators, washing machines, pumps, and lighting. Refrigerators ownership approaches near-universal access; fans reach full penetration early; and lighting fixtures per household increase around 5 times by 2070.

Rapid appliance adoption, especially space cooling, will sharply raise electricity demand and peak loads, particularly in hot seasons and evening hours. If met with conventional supply and leaky envelopes, this could heighten emissions and stress grids. However, this is also a design opportunity to invest now in energy-efficient building design and appliances, smart cooling and lighting systems, rooftop solar, storage, and modernised grids.

x Person cooling degree days is the country's average annual cooling degree days (CDD) multiplied by its population. CDD is the difference between the mean daily temperature (average of the daily high and daily low) and a reference or base temperature (18 °C in this instance)

Important Policy interventions

i. **Passive design at scale:** Directional orientation, natural ventilation, shading, cool roofs, and insulation to ensure new stock is heat-resilient by default.

ii. **Codes & standards:** Credible enforcement of building codes (Energy Conservation and Sustainable Building Codes, and Eco-Niwas Samhita); tighter Minimum Energy Performance Standards (MEPS) and labels for RACs, refrigerators, fans, motors, and lighting.

iii. **High-efficiency diffusion:** Bulk procurement and incentives for super-efficient RACs; quality assurance for inverters/refrigerants.

iv. **Demand-side management:** ToD tariffs, smart controls, and utility programmes to shift or shave cooling peaks.

v. **Low-carbon materials and retrofits:** Fly-ash or green concretes and envelope upgrades to cut lifetime cooling needs.

Industrial Demand- Scale, Catch-up and Clean Energy Pathways

India's industrial production will grow rapidly to meet the demand for urbanisation, infrastructure, housing, transport, and manufacturing. The growth is driven by steel, cement, aluminium, and plastics among others, and whose output is projected to multiply several-fold by 2070.

India's per-capita consumption of many industrial commodities today is much lower than the global averages. Figure 3.4 shows the per capita consumption of a few key commodities as a function of GDP per capita. For instance, India's steel consumption is 103 kg/capita as against the world average of 222 kg/ capita and China's ~630. India's cement consumption is 260 kg per capita (world average 549; China 1,650). Finally, India's aluminium consumption is 3.6 kg per capita (world average ~28).

As incomes reach USD 18,000+ per capita, India's steel use is projected to increase to 356 kg per person, approaching the current EU average, while cement consumption nears 921 kg per person. Aluminium use is projected to increase nearly fourfold to 16 kg per person, aligning with today's world averages. Total steel consumption is projected to reach about 568 million tonnes by 2047, while cement demand is expected to approach 1,471 million tonnes. Aluminium use is projected to increase to around 25 million tonnes by 2047 (see Figure 3.5).

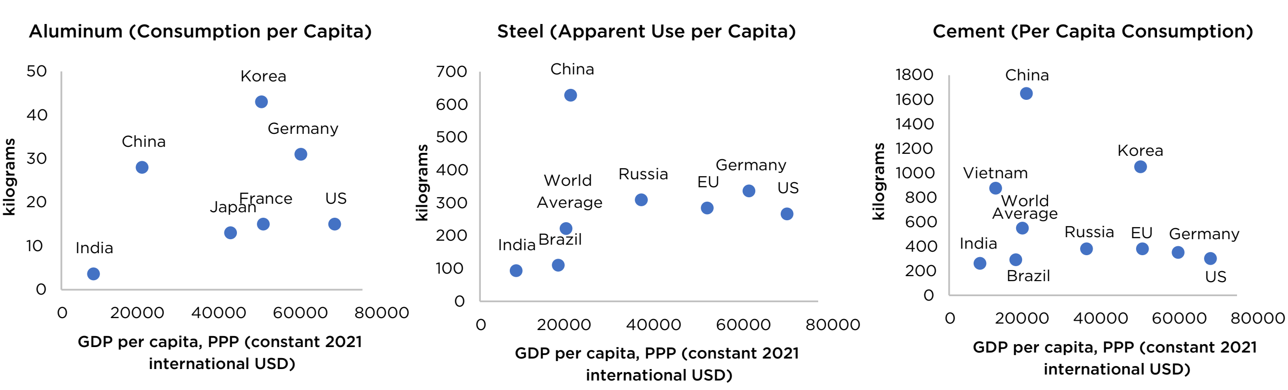


Figure 3.4: Per-capita commodity demand vs per-capita GDP

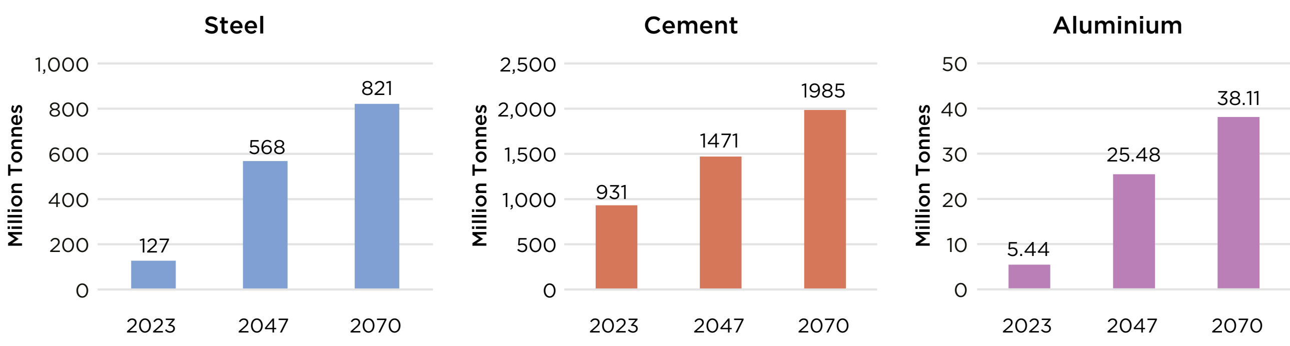


Figure 3.5: Projected industrial demand of select commodities- steel, cement, aluminium (million tonnes) by 2047 & 2070

India's share of world production is expected to increase sharply, with 25% of global steel, ~20% of aluminium, and ~34% of cement Made in India by 2050. This positions India as a central node in global supply chains. It also intensifies resource and energy demands. The implication is twofold: opportunity (market share, jobs, and technology upgrading) and obligation (resource productivity, energy efficiency, and compliance with emerging carbon standards).

It is important to emphasise that while the per capita use increases, the objective is not to maximise consumption; instead, it is to meet needs sustainably and resource-efficiently. The policy emphasis is on circular economy, low-carbon technologies, strategic resource planning, and demand-side measures (material-efficient design, lifecycle optimisation, and gradual shifts toward less material-intensive services). This is to ensure that higher living standards do not translate into a corresponding raw-material intensity.

A major push to secondary production is expected to raise scrap's share, in steel from 20% in 2025 to 40%, by 2070, and in aluminium from 30% to 40% by 2070. This is backed by formal scrap markets, better collection logistics, and scaled recycling capacity. In parallel, production can be decarbonised via efficiency, electrified heat where viable, green hydrogen for hard-to-abate routes, and carbon capture for process emissions, notably in cement. Credible standards/ Monitoring Reporting and Verification (MRV) and cluster infrastructure can keep Indian industry productive, competitive, and climate-aligned, turning scale into an advantage rather than a liability.

Mobility Demand- Scale, Saturation and Shift to Efficient Modes

India has a low mobility base of ~4,107 passenger kilometres (PKM) per capita as compared with the United States (~20,428), Italy (~14,956), and Thailand (~10,435). Freight transport in India is 2,990 tonnes kilometre (TKM) per capita, well below advanced-economy benchmarks. With rise in per-capita income and urbanisation, mobility is expected to increase as seen in other developed economies.

As the economy and cities expand, passenger and freight activity are expected to grow nearly 4.5 times from 2023 levels before saturating at mature-economy ranges. Under Current Policy Scenario, PKM per capita is expected to rise from 4,107 passenger kilometres per capita in 2023 to 14,000 by 2070. Under Net Zero Scenario, better planning and management i.e., adoption of Transit-Oriented Development (ToD), leads to saturation at 12,000 PKM per capita, lower than Current Policy Scenario. This is still a dramatic expansion in access, but with lower lifetime emissions and reduced infrastructure strain. Even by 2070, India's per-capita passenger mobility remains below that of the United States. It is broadly in line with European countries, reflecting demographics and deliberate choices (see Figure 3.6).

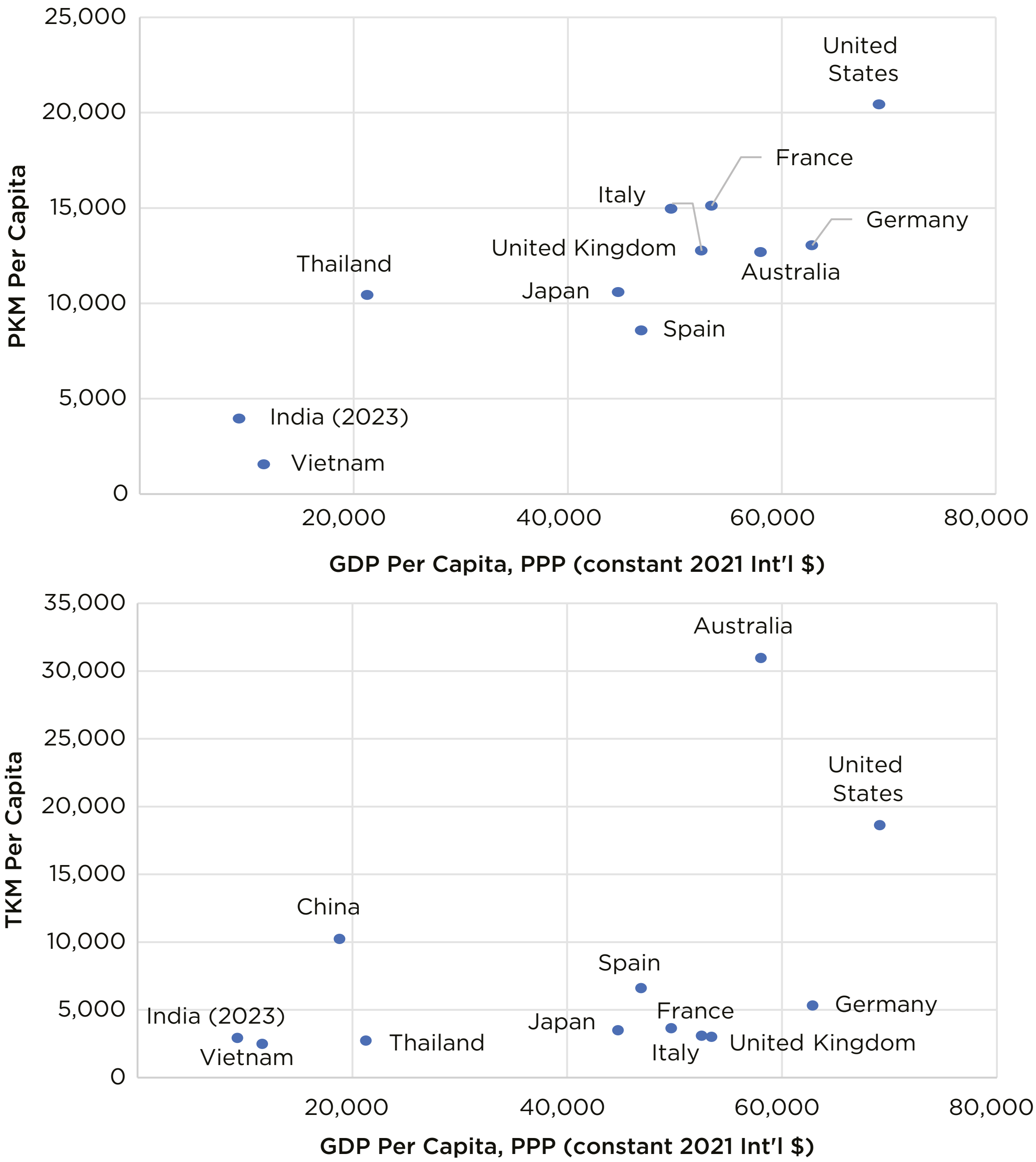


Figure 3.6: Transport demand (Passenger kilometre per capita v/s GDP per capita), and (Tonnes kilometre per capita v/s GDP per capita)

Left to a road-dominated, fossil-intensive trajectory, the mobility surge could lock-in congestion, air pollution, and energy security risks. The developmental strategy should counter this through Mission LiFE, compact transit-oriented development (TOD), shared mobility, and non-motorised transport (NMT), moderating demand without compromising access.

Modal shift and enabling capacity. In passenger transport, the share of road travel is projected to fall from 78% in 2025 to 64% by 2070, while rail and metro share rise to 25% and 4% respectively. In freight, the road share is expected to drop from 66.4% in 2025 to 60%, with rail and waterways taking on a greater role. Supporting this shift will be a 5 times expansion in metro rail length (to over 5,000 kms), a tripling of aviation capacity, and the development of 7,000 km of high-speed rail. These interventions are designed to meet mobility demands while reducing emissions and improving overall system efficiency.

Car ownership is expected to rise from about 32 cars per 1,000 people (2023) to about 200-250 cars per 1,000 by 2070. This is a huge increase in the number of vehicles on road. This is comparable with the present car ownership in China (~231), but far below than the United States (~850). This highlights the urgency of scaling up public transport, compact urban planning, and clean-mobility solutions.

Conclusion

The sectoral developmental choices outlined here are not constraints on growth but enablers of sustainable prosperity. They translate the abstract goal of Net Zero by 2070 into tangible, sector-specific actions that align with India's broader development priorities. For instance, providing universal housing with thermal comfort, expanding mobility access without urban gridlock, scaling industrial output to meet infrastructure and consumption needs while minimising material waste, and ensuring energy access that is affordable, reliable and clean.

The rising demand for housing comfort, mobility, industrial goods, and services outlined in this chapter will create unprecedented energy demand, but also a defining opportunity to reshape how that energy is produced, distributed, and consumed. The next chapter quantifies this energy transformation: it examines how a 2.5-fold growth in floor space, near-tripling of industrial output, and a 4.5-fold expansion in mobility translate into energy requirements and emissions.

4

INDIA'S TRANSITION PATHWAYS

India's Transition Pathways

4

This chapter presents the consolidated results of the integrated energy sector model developed for India, reflecting the development pathways and policy choices outlined in preceding chapters. Building on the methodological framework described in Chapter 2 and sectoral development trajectories and economic growth detailed in Chapter 3, the analysis now transitions from assumptions to system-wide outcomes.

The chapter quantifies India's energy transformation across three interconnected dimensions: Final energy demand by sector (industry, transport, buildings, and agriculture), primary energy supply by fuel (coal, oil, gas, nuclear, renewables, and bioenergy). It compares two pathways described in Chapter 2: The Current Policy Scenarios (CPS), which extends today's policy landscape, and the Net Zero Scenario (NZS) aligned with India's 2070 Net Zero commitment.

4.1 FINAL ENERGY DEMAND

India's final energy demand[xi] is projected to grow from 688 Mtoe in 2025 (estimated) to 1,617 Mtoe by 2050 and 1,811 Mtoe by 2070 under Current Policy Scenario, reflecting industrialisation, urbanisation, and economic growth (see Figure 4.1). Under Net Zero Scenario, this trajectory is moderated, with final energy demand reaching 1,381 Mtoe in 2050 and 1,465 Mtoe by 2070, a reduction of 19% compared to CPS in 2070. This reduction is driven by systematic efficiency improvements, large-scale electrification of end-use sectors, greater circularity in material uses and targeted demand moderation, enabling India to meet its developmental goals with reduced energy (see Figure 4.1).

xi This includes direct fuel (fossil and biofuel) use to end-use sectors for energy and non-energy purposes, electricity (utility + captive) use and Green Hydrogen.

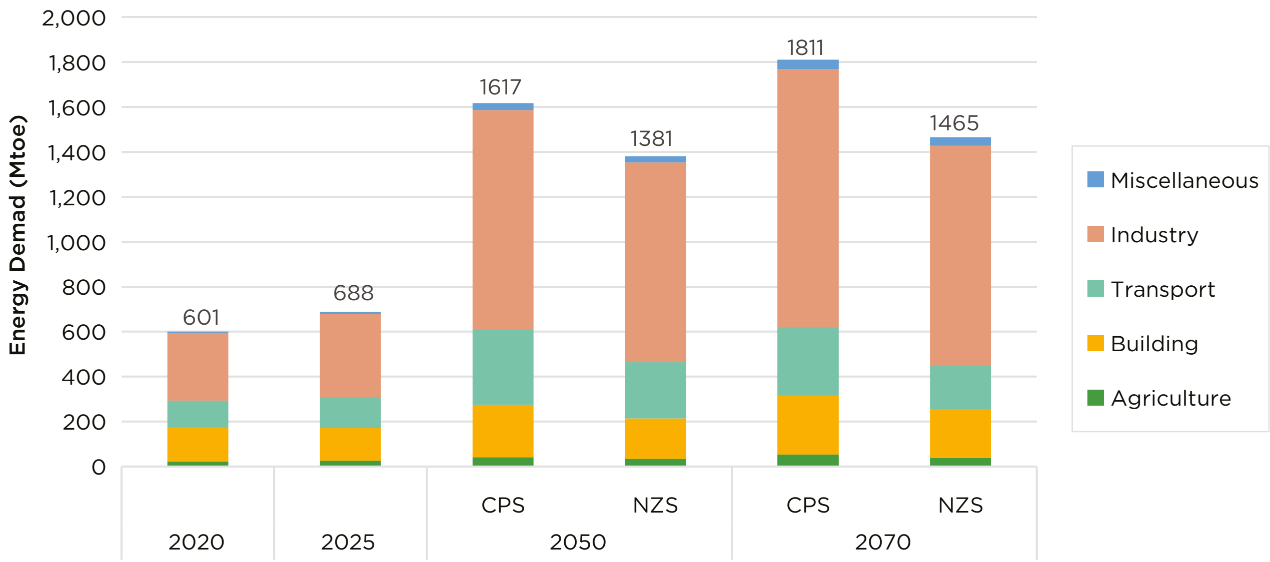


Figure 4.1: Final Energy Demand Projections, Mtoe

The shift from 2050 to 2070 marks a structural transition: Beyond mid-century, India enters a post rapid development phase where per-capita demand for materials and transport slowly saturates, slowing aggregate energy growth. Incremental demand shifts from infrastructure build-out to services and lifestyle diversification, while energy intensity per unit of GDP continues to fall. Under Net Zero Scenario (NZS), the increase is only marginal post-2050 due to the impact of higher energy efficiency improvement and greater electrification compared to Current Policy Scenario (CPS).

Industry becomes the dominant force in India's energy demand, with its share rising from 53% in 2025 to 63–67% by 2070. This surge is driven by rising per-capita consumption of steel, cement, and aluminium, moving from a low base towards global norms. As a result, total fuel consumption increases by more than 3 times in CPS and more than 2.5 times in NZS, making industry the most influential driver of energy demand growth over the coming decades. However, the scale of this increase is significantly moderated by declining energy intensity across industries, driven by electrified process heat, penetration of green hydrogen, improved material efficiency, and circular economy practices, limiting energy demand from rising in proportion to output growth.

The transport sector illustrates the broader transformation. Despite rising passenger and freight activity, overall energy demand from transport grows more slowly as the system becomes progressively more efficient. Rapid electrification of vehicles, continued efficiency improvements in internal combustion engines, and a structural shift toward public and shared mobility moderate energy requirements. These combined changes enable a clear decoupling of transport energy demand from mobility growth, supporting lower overall energy use even as movement of people and goods expands.

Emerging Demand Scales Rapidly While Conventional Miscellaneous Loads Streamline: Conventional public energy uses, such as street lighting, water pumping, and municipal services, remain a small share of final energy demand but become far more efficient with LEDs, smart controls, and variable-speed drives. By contrast, emerging demand grows rapidly: data centres are projected to add an electric load of 45 GW by 2050 and 80 GW by 2070, supported by lower power usage effectiveness (PUE), liquid cooling, waste-heat reuse, and flexible operations. Cold chains for food and pharmaceuticals also expand, backed by high-efficiency compressors, low-Global Warming Potential (GWP) refrigerants, and thermal storage, allowing growth without proportional energy use.

Demand electrification accelerates: Electrification emerges as a cornerstone of India's energy transition, becoming the dominant mode of delivering energy services. Electricity's share of final energy demand rises from 21% in 2025 to 32% by 2050 and 40% by 2070 under the Current Policy Scenario (CPS). In the Net Zero Scenario (NZS), the electrification is even more; 42% in 2050 and 60% in 2070. (See Figure 4.2).

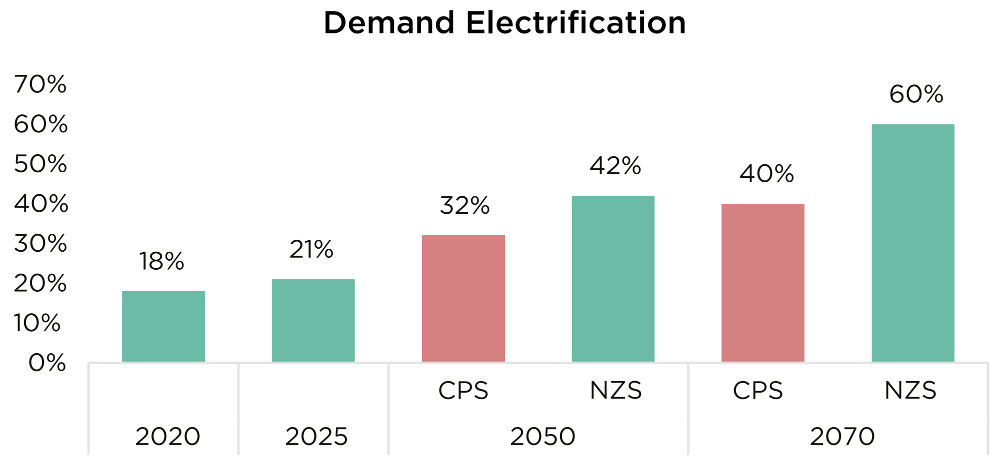


Figure 4.2: Electricity's share of final energy demand (in %) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

4.2 PRIMARY ENERGY SUPPLY

This section discusses the energy supply mix to meet the energy demand in both the Current Policy and Net Zero scenarios (see Figure 4.3). Primary energy supply increases from 1,006 Mtoe in 2025 (estimated) to 2,492 Mtoe in the CPS, and 2,159 in the NZS by 2070.

This growth is paired with a fundamental shift in India's energy mix. In 2025, fossil fuels provide 87% of primary energy. Under NZS, this pattern reverses: non-fossil-fuel sources contribute 86% of the primary energy supply. The share of fossil fuels declines to 14%, largely confined to hard-to-abate sectors such as aviation, shipping, and industrial heat and feedstock use. Under CPS, the transition is slower, with fossil fuels still contributing 54% of the energy mix by 2070.

This transformation reflects more than a fuel switch; it marks a structural evolution. The increase in electricity consumption in final energy enables deep Renewable Energy (RE) penetration and a larger role for nuclear power across both scenarios. As a result, the share of non-fossil fuels in primary energy rises from 5% in 2025 (excluding traditional biomass) to 46% in the CPS. In the NZS, the share of non-fossil fuels is 86% (61% higher compared to CPS) by 2070.

RE transitions from a supplementary energy source to become the backbone of the energy system, with the CPS following the same structural direction but at a much slower pace. This rapid expansion of RE across both scenarios is primarily driven by a sustained decline in technology costs, including the cost of energy storage. This indicates that the growth of renewables is mainly driven by market economics and not due to any targeted policy measures.

By 2070, fossil fuel shares in Current Policy Scenario (CPS) are coal at 30%, oil at 16%, and gas at 8%, while renewables reach 32%. In NZ Scenario, the share of coal, oil and gas is 3%, 7% and 4%, respectively, while RE contributed 63% by 2070. This divergence highlights the transformative impact of NZS interventions, including higher electrification, ambitious renewable deployment integrated with energy storage, and nuclear energy to provide base-load power, an accelerated transition in just five decades.

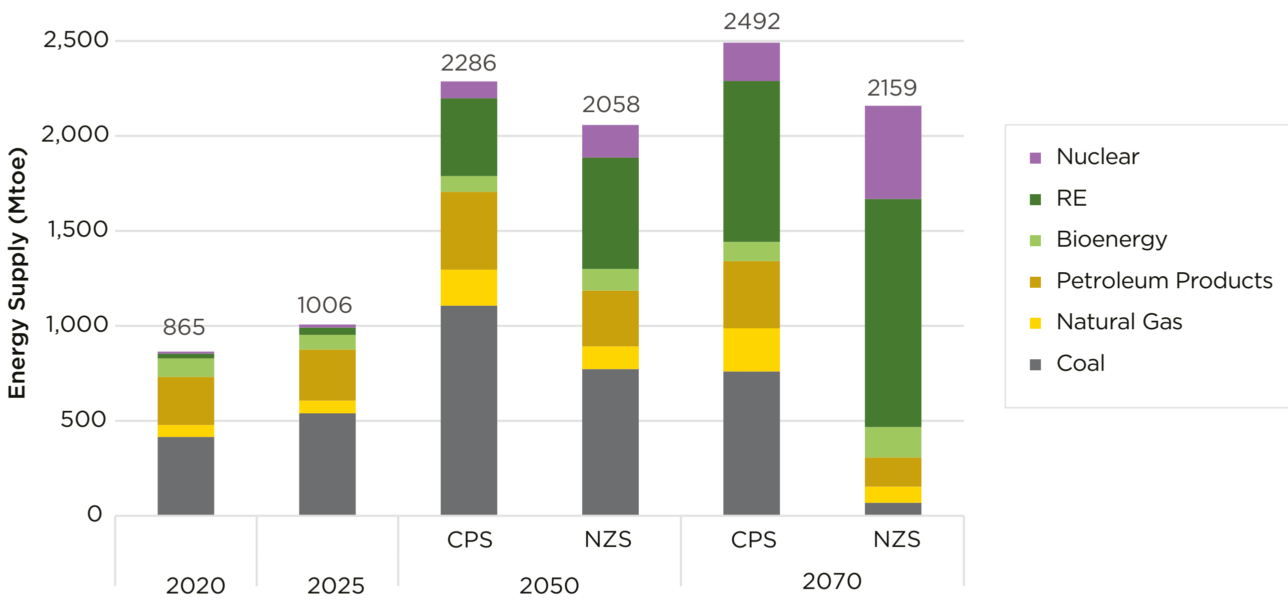


Figure 4.3: Primary energy supply projections under Current Policy Scenario (CPS) and Net Zero Scenario (NZS) for 2050 and 2070, Mtoe

Nuclear energy, emerges as a strategic pillar, growing from 2% energy in 2025 to 8% by 2050 (~100 GW capacity) and 23% by 2070 under the Net Zero Scenario (NZS), delivering round-the-clock, low-carbon firm power. In the Current Policy Scenario (CPS) nuclear energy reaches 8% share by 2070, Net Zero Scenario follows an earlier large-scale deployment and enhances grid reliability–including the use of small modular reactors (SMRs), making nuclear a critical enabler of low-carbon energy transition.

At present, traditional biomass is a considerable component of primary energy (11%). It is largely used for cooking, mostly in rural areas. Going forward, traditional biomass is expected to progressively reduce as households transition to cleaner, more efficient fuels, such as LPG. Use of traditional biomass for energy is expected to be eliminated by mid-century. There will be an increase in other bioenergy sources, such as biofuels and biogas in transport, biochar and feedstock in industry sourced from agricultural residues and municipal solid waste. By 2070, bioenergy is expected to contribute 7% of primary energy in the NZS. However, under CPS, modern bioenergy reaches only 3% by 2070, constrained by slower progress in waste management and feedstock processing.

Under Net Zero Scenario (NZS), natural gas contributes 6% of primary energy in 2050 but is expected to decline to 4% by 2070 as electrification and green hydrogen displace its role in the transport and cooking sectors. This reflects the nature of natural gas as a transitional fuel in NZS and the importance of partial repurposing of planned infrastructure. However, gas remains as an energy source with 9% share by 2070 under Current Policy Scenario (CPS), reflecting a slow transition, where gas continues to be leveraged.

Together, these shifts reflect a structural evolution where clean electricity, efficiency, and targeted policy drive India's energy transition while supporting its development goals.

Box-4.1: *The Net Zero transition creates a power-centric, renewables-led (supported by energy storage and nuclear energy) system that enhances energy security through greater reliance on indigenous resources while reducing exposure to imported fuels. However, it demands commensurate investment in clean technologies: green hydrogen, energy storage, advanced nuclear reactors, robust transmission infrastructure (including HVDC corridors), and advanced digital grid operations to manage variability and integration challenges.*

4.2.1 Fuel Demand

Coal

India's coal demand is expected to follow two distinct trajectories depending on the policy pathway adopted (see Figure 4.4):

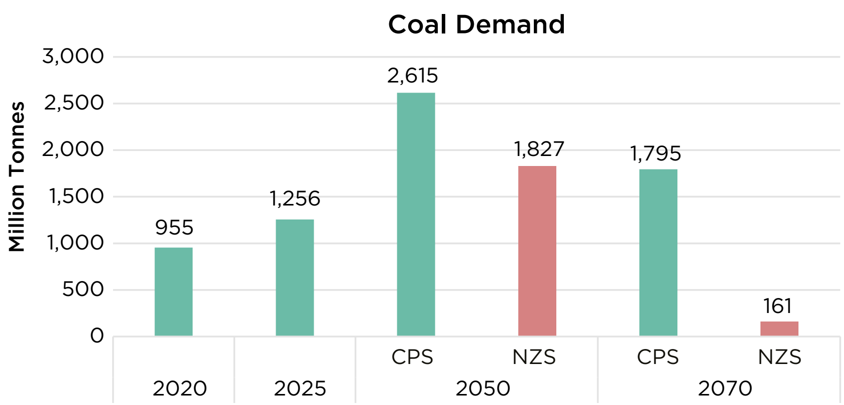


Figure 4.4: Projected coal demand under Current Policy Scenario (CPS) and Net Zero Scenario (NZS) for 2050 and 2070, Million tonnes

Under the Current Policy Scenario (CPS), coal demand is projected over the long-term to be 2,615 million tonnes (Mt) in 2050 and 1,795 Mt in 2070. The share of coal reduces from 73% in 2025 to 47% in 2070, even in CPS, driven by higher penetration of renewable energy, driven by commercial considerations.

In contrast, the Net Zero pathway envisages a moderate coal trajectory. Coal demand is projected to be to 1,827 Mt in 2050 and 161 Mt in 2070, a substantial divergence from the CPS. As the power sector transitions largely to non-fossil fuel-based electricity, the residual coal majorly serves industrial load. These industrial loads are in hard-to-abate sectors such as steel and cement, where viable low-carbon alternatives are still emerging. Crucially, all remaining coal use in 2070 will have to be paired with carbon capture, utilisation, and storage (CCUS) to achieve Net Zero emissions.

Across both scenarios, India's abundant coal reserves combined with potential CCUS deployment could provide opportunities for cleaner coal utilisation. Technologies such as advanced ultra-supercritical plants, coal gasification, and coal-to-chemicals (e.g., methanol, ammonia) can offer lower-carbon pathways – especially when integrated with carbon capture and storage technologies.

Oil

India's oil demand is projected to follow divergent paths under the Current Policy Scenario (CPS) and Net Zero Scenario (NZS) (see Figure 4.5).

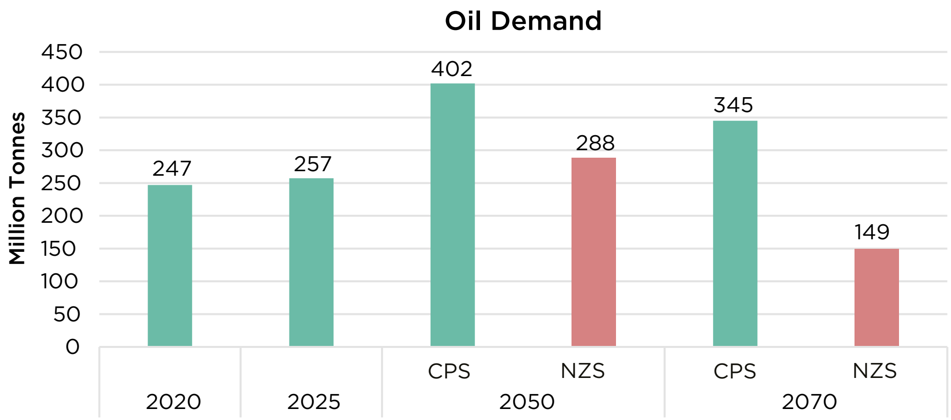


Figure 4.5: Projected Oil demand under Current Policy Scenario (CPS) and Net Zero Scenario (NZS) for 2050 and 2070, Million tonnes

Under CPS, oil demand continues to grow, reaching approximately 402 Mt by 2050, slightly tapering down to 345 Mt in 2070. This sustained demand is driven by continued reliance on conventional fuels and slower electrification, particularly in road transport and industry.

In contrast, the NZ pathway reflects a more moderate demand trajectory, with a total demand of 288 Mt in 2050, tapering down to 149 Mt in 2070. Of the remaining 149 Mt in 2070, 27% is consumed in the transport sector, primarily to cater long-haul shipping and aviation demand. A substantial share of 69% is used in Industry sector, mainly as feedstock in the chemical industry, as fuel in other industry application and as pet coke in cement sector. The remaining 4% is attributed to the cooking sector, largely in rural areas.

The two pathways present very contrasting roles of oil in future. While under the Current Policy Scenario, oil continues to play a broad and growing role across the economy, its use steadily narrows to a few essential areas in transport and industry under the Net Zero Scenario. However, even in the NZS, oil still remains in the economy. This highlights that the transition is less about eliminating oil quickly and more about reducing its use where cleaner alternatives become viable.

Natural Gas

In Current Policy Scenario, gas demand is expected to rise and reach 205 BMSCM in 2050 and 246 BMSCM in 2070 (see Figure 4.6), driven by continued reliance on gas in industry (54%), transport (36%) and cooking sectors (9%).

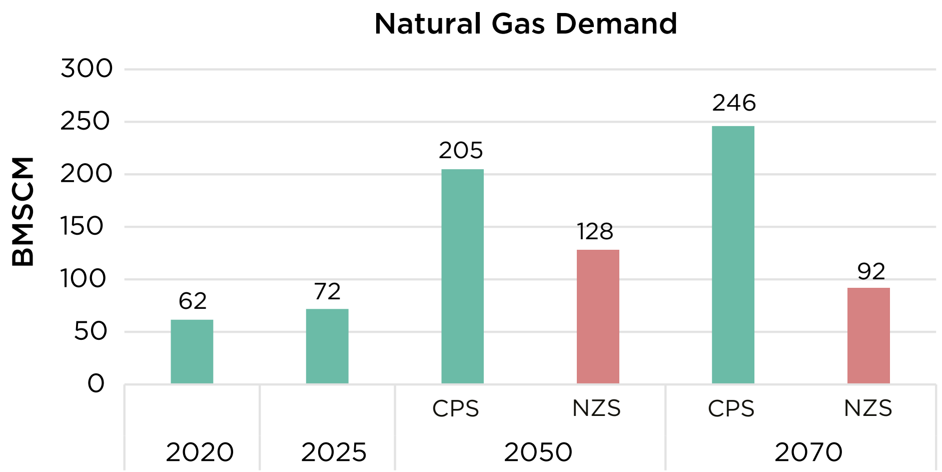


Figure 4.6: Projected natural gas demand under Current Policy Scenario (CPS) and Net Zero Scenario (NZS) for 2050 and 2070, Billion Metric Standard Cubic Metre (BMSCM)

In Net Zero Scenario (NZS), natural gas serves as a transitional fuel, rising through the 2030s to support cleaner transport reaching around 128 BMSCM in 2050 and tapering to 92 BMSCM by 2070 as electrification and low-carbon fuels scale. The residual uses in NZS includes 90% in Industry (majorly as feedstock in chemicals and fertilisers), and 10% in the cooking sector. It is important to note that in NZS, the natural gas demand in 2070 exceeds the present demand.

Given this divergence, planned LNG and CNG infrastructure must be future-proofed. Designing these assets to be hydrogen- and biomethane-ready is essential to avoid long-term lock-in and to enable a smoother transition toward Net Zero goals.

Green Hydrogen

Green Hydrogen is likely to become a key clean energy carrier wherever direct electrification falls short. From a near-zero green baseline today, the pathways diverge sharply (see Figure 4.7). Under Current Policy Scenario, green hydrogen use is projected to grow gradually to around 8 million tonnes by 2050 and 24 million tonnes by 2070, largely supplementing fossil-based production. Under the Net Zero Scenario, deployment is projected to accelerate, reaching 25 million tonnes by 2050 and doubling to 50 million tonnes by 2070. This growth is anchored via hydrogen-based reduction in steelmaking, green ammonia for fertilisers, cleaner process hydrogen in refineries, use of its derivatives e-methanol and ammonia for shipping, a small amount going to buses and heavy-duty vehicles and a tradable molecules platform supporting exports.

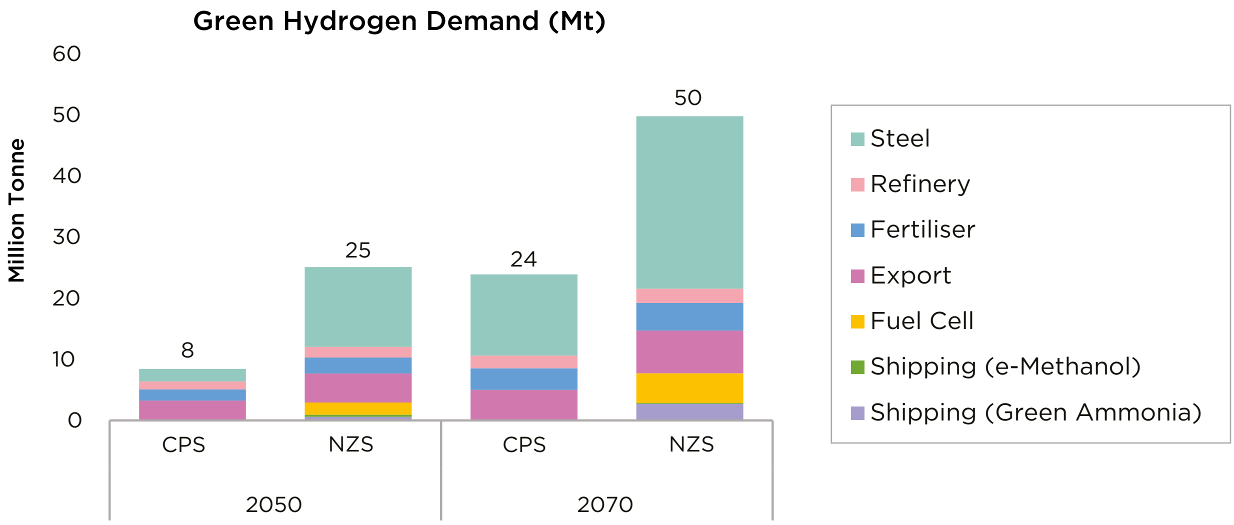


Figure 4.7: Projected green hydrogen demand for various end-use sectors under Current Policy Scenario (CPS) and Net Zero Scenario (NZS) for 2050 and 2070, Million tonnes

The power system implications of green hydrogen are significant. Assuming that most of the Green Hydrogen is from water electrolysis, the Current Policy Scenario (CPS) will require about 470 TWh additional electricity generation in 2050 and 1,331 TWh by 2070. Under Net Zero Scenario (NZS) electricity demand for green hydrogen is projected to be 1,392 TWh in 2050 and 2,764 TWh in 2070. This firmly links hydrogen deployment to clean power expansion and long-term electricity market reforms, including open access, long-tenor PPAs, and robust storage mechanisms.

Biofuels

Biofuels play a key transitional role in both scenarios, though their scale and application vary (see Figure 4.8). India's rapid ethanol expansion, reaching 20% blending with petrol by mid-2025 (around 10 billion litres), five years ahead of target, demonstrates how policy, supply chains, and demand can align to accelerate clean fuel adoption.

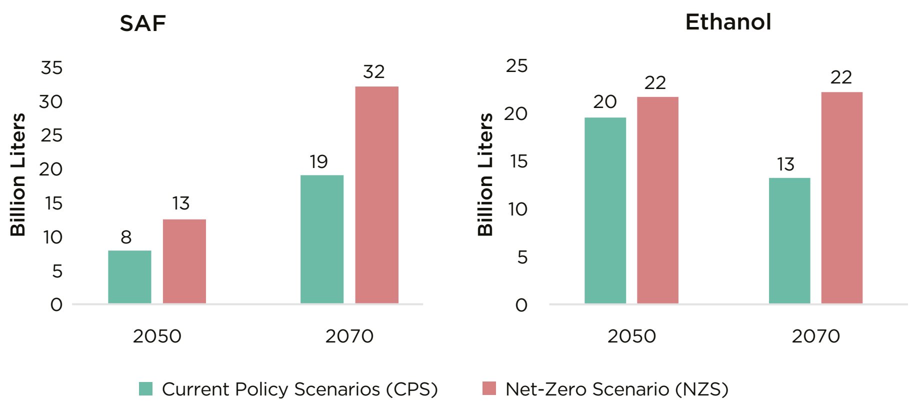


Figure 4.8: Projected demand of select biofuels (Sustainable Aviation Fuel (SAF), and Ethanol) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS) for 2050 and 2070

Under the Current Policy Scenario (CPS), biofuels remain largely confined to road transport. Ethanol peaks near 21 billion litres by the mid-2040s. Bio-CNG adoption remains modest, playing only a niche role in select citygas and transport applications. By contrast, Sustainable Aviation Fuel (SAF) uptake grows more significantly from a very low base, reflecting offsetting requirements on international flights.

In the Net Zero Scenario (NZS), biofuels use is higher. Ethanol reaches around 22 billion litres post-2050, supported by flex-fuel vehicles reaching 10% of car sales by 2050. Sustainable Aviation Fuel (SAF) grows to 32 billion litres by 2070, helping low-carbon transition in aviation.

India's biofuel production currently relies on first-generation feedstocks like sugarcane, maize, and vegetable oils, which scaled quickly due to mature technologies and blending mandates. However, these sources face limits due to land and water use, food-security concerns, and seasonal variability. To sustain growth, future strategies must include feedstock caps, resource-efficiency standards, and a shift toward second-generation residues and advanced biofuel technologies to avoid long-term resource lock-in.

Box-4.2: Biofuel Supply Potential in India

India's ethanol production currently relies mainly on maize (~50%) and sugarcane (~30%), with the remainder coming from damaged food grains and other sources. According to the NITI Aayog Crop Husbandry Report on Demand and Supply (2024), by 2047–48, India's food grain production is expected to exceed domestic demand, creating a surplus of over 40 million tonnes. This potential surplus could support ethanol production of more than 16 billion litres, which would cover a substantial portion of the expected ethanol requirement of around 22 billion litres, indicating feedstock availability for higher blending goals without compromising food security.

Beyond ethanol, there is also notable potential for other biofuel pathways. For Compressed Bio-Gas (CBG), The International Energy Agency (IEA) estimates India's biogas potential at around 87 Billion Cubic Metres (BCM), suggesting significant scope for gaseous biofuels in transport sector. For SAF, the Feasibility Study on the Use of Sustainable Aviation Fuels in India (conducted under the ICAO ACT-SAF Programme) indicates significant potential for developing a domestic SAF industry, with production estimates cited around 41.5 billion litres. At the same time, competing biomass uses will persist, requiring careful assessment of trade-offs related to cost, energy balance, water use, and emissions.

4.2.2 Energy-GDP Decoupling

India's projected development trajectory for 2025–2050 can leverage on historical lessons and emerging opportunities. Figure 4.9 visually captures this by comparing 25-year development phases of the USA and China: the USA's post-war industrialisation (1960–1985), China's rapid manufacturing-led growth (2000–2025). We also compare this with India's projected pathways under the Current Policy and Net Zero scenarios.

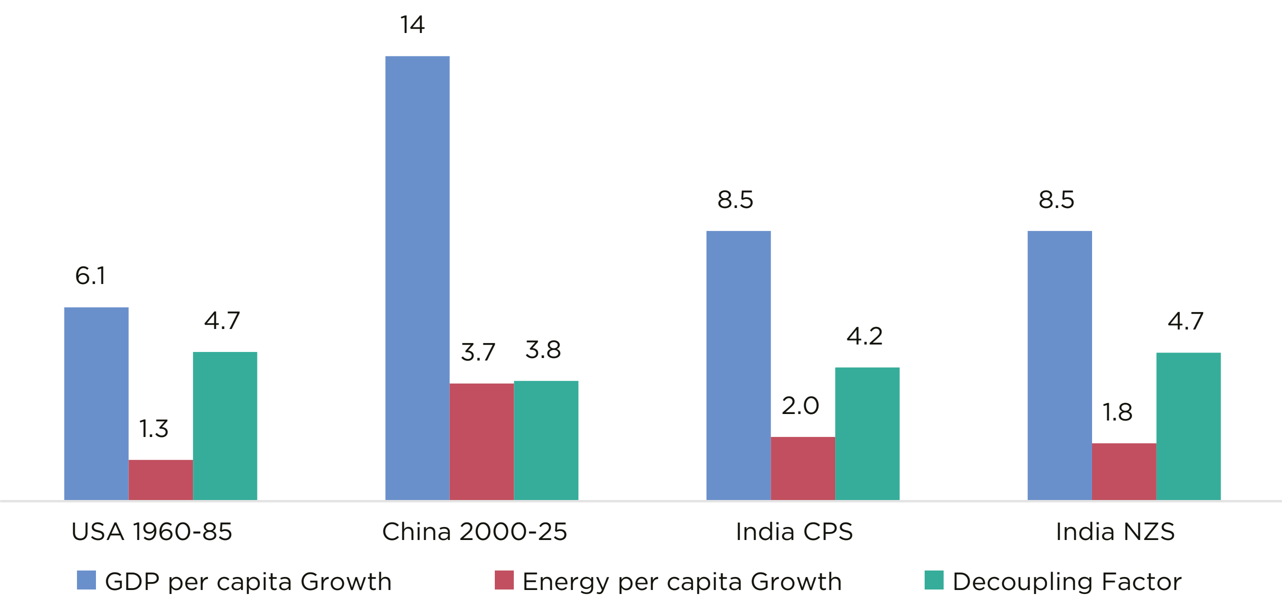


Figure 4.9: Historical trends of energy and GDP decoupling for select countries and comparison with India's projections for period 2025-2050 under CPS and NZS

The USA's experience shows strong GDP per capita growth during 1960-1985 (about 6.1 times), while energy use per capita rose only 1.3 times, yielding a decoupling factor of 4.7. This period marks a shift toward a service-driven economy, where growth has become less energy-intensive.

China's path contrasts sharply, with GDP per capita rising 14-fold during 2000-2025. However, energy use increased 3.7 times, resulting in a lower decoupling factor of 3.8. This underscores the energy-heavy nature of its rapid industrialisation, largely powered by coal.

Taken together, the experiences of the USA and China show that even when GDP per capita grows several-fold, energy use per capita tends to increase at a slower pace, indicating that a decoupling is possible between economic growth and energy consumption. This decoupling reflects a combination of structural economic shifts, improvements in energy efficiency, technological progress and change in composition of growth, from heavy industry towards services in the case of the USA and towards more efficient industrial processes in the case of China.

Against this backdrop, the Current Policy Scenario for India estimates that as GDP per capita grows 8.5 times by 2050, energy per capita expands 2 times, achieving a decoupling factor of 4.2. In the Net Zero Scenario the decoupling factor rises to 4.7 with a slightly lower energy growth of 1.8 times. This suggests India is also likely to progressively decouple GDP growth from energy use through strategic choices on technology and energy mix.

While the decoupling of energy growth from GDP observed in the chart demonstrates India's strong efficiency trajectory, the pattern for emissions is less straightforward. In both the US and China, absolute per capita emissions increased during their industrial transitions, even as energy-GDP decoupling improved.

Energy Intensity of GDP and Per-Capita Energy Trajectories

Structural changes can lead to improvements in energy intensity of GDP and energy consumption per unit of GDP. By 2050, India’s energy intensity is projected to fall to 39-43% of the 2025 level. It further reduces to 20-23% by 2070 as compared with the 2025 level (see Figure 4.10). This decline from around 0.22 MJ/INR in 2025 to approximately 0.04-0.05 MJ/INR by 2070 reflects improvements in energy efficiency, greater electrification, technology upgradation, process optimisation and adoption of cleaner and more efficient production methods across the economy.

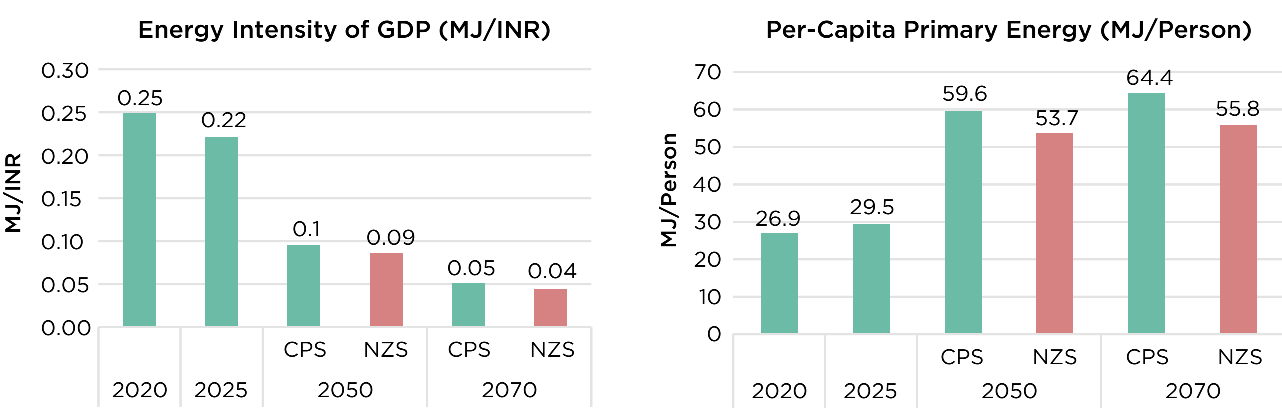


Figure 4.10: Projections of India’s energy intensity to GDP (Mega Joules per INR) (left) and per-capita primary energy (Mega Joules per person) (right)

Per-capita primary energy consumption (see Figure 4.10) is projected to rise with income from about 30 GJ per person in 2025 to 60 GJ per person in 2050 and 64 GJ in 2070 under the Current Policy Scenario (CPS). It is expected to be lower at 54 GJ per person in 2050 and 56 GJ per person in 2070 under the Net Zero Scenario (NZS). Even at this level, India’s per-capita consumption remains below the current world average of 75.4 GJ per person, and well below OECD benchmarks (typically 125.6–167.4 GJ/person), reflecting population scale and efficiency gains.

The declining energy intensity is a metric of success–it means India is getting more economic output from each unit of energy, essentially “doing more with less”. This reduction facilitates the pathway to Net Zero by lowering total energy (and hence the magnitude of the decarbonisation task). It also delivers economic benefits: a less energy-intensive economy is more competitive and less vulnerable to energy price swings. The rise in per-capita energy use, on the other hand, signals improved prosperity with people accessing more electricity, mobility, and modern fuels, which is a positive, but must be met through efficient and sustainable forms of energy to support long-term growth.

4.3 ELECTRICITY

Electricity becomes the main channel for energy services: India’s total electricity consumption (utility + non-utility) is projected to grow from 1,541 TWh in 2024 to 8,070 TWh in the Net Zero Scenario (NZS) compared to 6,550 TWh under the Current Policy Scenario (CPS) by 2050, and

13,000 TWh under the NZS as compared to 9700 TWh under the CPS by 2070 (see Figure 4.11). It is important to note that projections for electricity follow a trend different from that of primary enegry (Figure 4.3). The total primary energy supply is lower under NZS as comapared to CPS, both by 2050 and 2070. As against this, the electricity consumption is higher in NZS because of deeper electrification across end-use sectors such as transport, industry, cooking, and greater utilisation of green hydrogen. This enables lower use of energy, owing to higher efficiency of electric technologies.

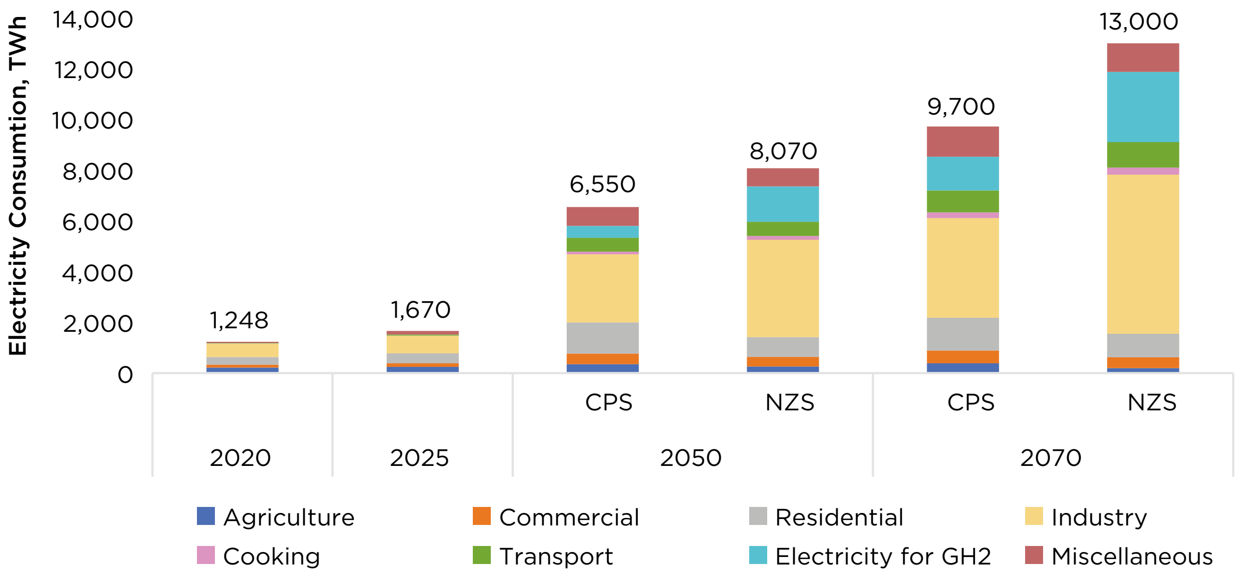


Figure 4.11: Projections of electricity consumption (TWh) under Current Policy Scenario (CPS) and Net Zero Scenario (NZS) for 2050 and 2070

Industrial electricity consumption is projected to increase from about 680 TWh in 2025 to 2,700 TWh under the Current Policy Scenario (CPS) and 3,850 TWh under the Net Zero Scenario (NZS) by 2050. By 2070, consumption rises further to 3,900 TWh in CPS and 6,300 TWh in NZS. Electricity demand for green hydrogen production is a major driver of this growth. It is projected to reach 470 TWh in CPS and 1,400 TWh in NZS by 2050, and 1,330 TWh in CPS and 2,765 TWh in NZS by 2070, with most of this demand coming from the industrial sector.

Even with faster electrification in the transport sector under the NZS, electricity demand in 2050 remains broadly comparable with CPS at around 550 TWh. This is because of lower overall travel demand per person and per unit of freight transport. By 2070, wider adoption of EVs under NZS leads to moderate divergence of electricity demand reaching about 1,000 TWh compared to 860 TWh in CPS.

Residential and commercial demand is projected to grow with greater use of appliances and cooling but remains lower in NZS due to improved efficiency, design and standards. Agriculture energy use electrifies efficiently, with solar pumps and electric tractors reducing diesel reliance. Together, these sectors reinforce the shift toward electricity while underscoring the importance of demand-side interventions.

4.4 EMISSIONS

The greenhouse gas emissions pathway reflects a development-oriented transition in which economic growth is progressively decoupled from emissions. This approach is embedded in the nationally determined climate strategy, which prioritises reductions in emissions intensity over absolute emissions, consistent with development needs, equity considerations, and differentiated responsibilities. Early progress demonstrates that significant efficiency gains and structural shifts can be achieved alongside economic expansion.

By 2020, India had already achieved an estimated 33% reduction in emission intensity compared to 2005 levels, demonstrating early progress toward its NDC targets. Across both policy pathways, emissions intensity continues to decline over time, with deeper reductions under more ambitious Net Zero mitigation scenarios. In the long term, this results in a clear decoupling of economic growth from greenhouse gas emissions, particularly under a Net Zero aligned transition. While emissions will increase in the medium term due to rising energy demand associated with development, the overall trajectory reflects improving energy efficiency, cleaner energy supply, and structural transformation of the economy. Overall, this development and equity-aligned pathway demonstrates that reductions in emissions intensity can be achieved alongside sustained economic growth.

4.4.1 Pillars of Transition

India's pathway to Net Zero rests on a portfolio of measures that cumulatively determines the emissions trajectory. The chart below (Figure 4.12) shows the relative contribution of different "pillars of transition" in reducing gross emissions from a Current Policy Scenario trajectory to the Net Zero outcome by 2070. Importantly, even after all these interventions, India will have resiual emissions of 22%. These can only be elmininated by carbon capture technologies.

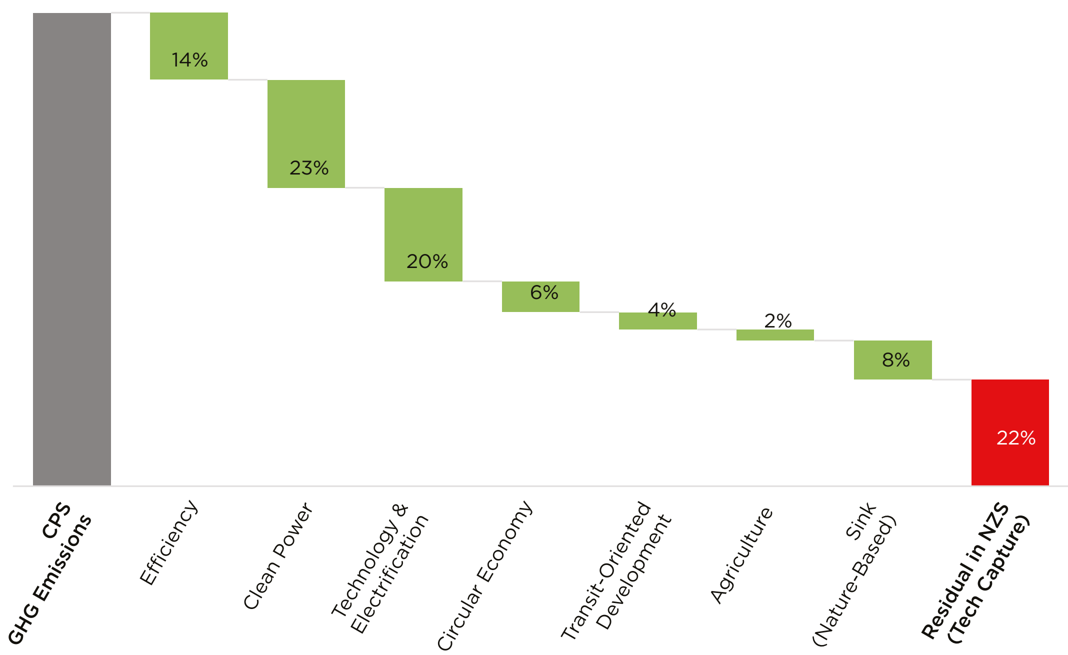


Figure 4.12: Key Levers to reduce GHG emissions from Current Policy Scenario to Net Zero Scenario by 2070

Demand-side Efficiency

Demand-side efficiency is the fastest and most cost-effective way to reduce emissions while supporting economic growth. It relies on improved performance standards for appliances and equipment, 5-star air conditioners, refrigerators, motors, pumps, and fans. It also includes enforcement of building codes like Energy Conservation and Sustainable Building Codes (ECSBC) and Eco-Niwas Samhita (ENS), alongside deep retrofits and smart controls to cut heating, cooling, and lighting loads.

In industry, best available technologies, including variable-speed drives, high-efficiency boilers and furnaces, energy management systems, and waste-heat, drive major efficiency gains. These are further amplified by behavioural shifts under Mission LiFE and digital optimisation through Interenet of Things (IoT) and Artificial Intelligence (AI).

Under Net Zero Scenario (NZS), sustained efficiency improvements contribute 14% of total emission reductions compared to Current Policy Scenario (CPS), avoiding ~0.86 $GtCO_2e$ annually by 2070, while lowering the scale and cost of new energy supply. Macroeconomic modelling shows India's energy intensity of GDP halves by 2047 and falls to one-fifth of today's level by 2070, reflecting cumulative efficiency gains and structural transformation.

Clean Power

Decarbonising the power sector is the foundation for economy-wide emission reductions, as a clean grid enables end-use electrification. Under the NZS, the grid's emission factor declines from 0.71 $kgCO_2/kWh$ in 2025 to 0.257 $kgCO_2/kWh$ in mid-century to near zero in 2060s, delivering the largest cut compared to CPS (Figure 4.13).

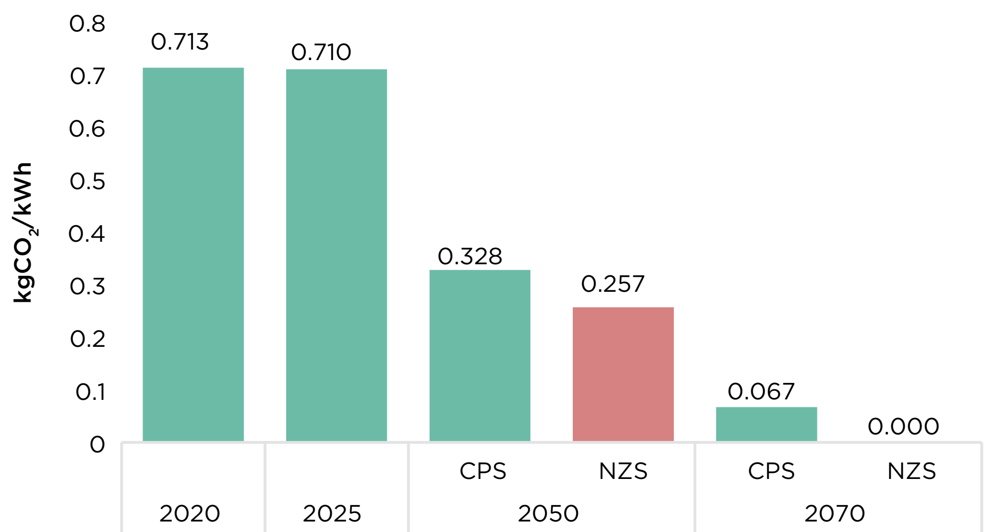


Figure 4.13: Projection of grid carbon intensity under Current Policy Scenario (CPS) and Net Zero Scenario (NZS) for 2050 and 2070 ($kgCO_2/kWh$)

Achieving this requires an unprecedented build-out of renewables with cumulative solar and wind capacity reaching 3,000-3,200 GW by mid-century and continuing thereafter, supported by large-scale battery and pumped-hydro storage. The share of nuclear as a source of firm baseload power rises to nearly 13% of supply by 2070. CPS retains around 6%-12% coal generation by 2070, whereas the NZS discontinues all unabated coal from dispatch, with 140-160 GW as reserve capacity.

Technology Switch & Electrification

Technology switch and end-use electrification replace millions of diffuse combustion sources with a rapidly decarbonising power system, shifting emissions from stacks and tailpipes to renewables, hydrogen, and modern bioenergy.

Under the Net Zero Scenario (NZS), electricity's share of final energy is projected to increase from 21% in 2025 to 60% by 2070 compared to 40% in Current Policy Scenario (CPS). In transport, oil use for road travel is projected to be nearly eliminated by 2070 as electric vehicles dominate, with green hydrogen and e-fuels mainly used for the hardest-to-electrify segments. In buildings, cooking energy is likely to shift to electric systems while space heating and cooling pivot to heat pumps and efficient appliances. Industry electrifies low and medium-temperature heat and motor systems, and green hydrogen supplies process heat for the most challenging applications, with a demand of 50 Mt demand by 2070. This pillar delivers roughly 20% of the overall emissions reduction by 2070.

Circular Economy and Material Efficiency

Circular economy strategies decouple growth from raw material use by maximising reuse, recycling, and material recovery. Under Current Policy Scenario (CPS), measures like extended producer responsibility (EPR), end-of-life vehicle (ELV) rules, and improved recycling deliver notable gains. The Net Zero Scenario (NZS) builds on this foundation with deeper interventions across key sectors.

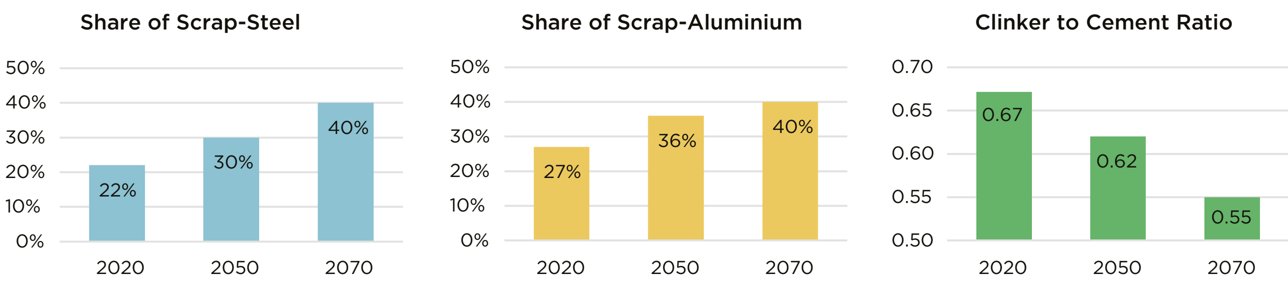


Figure 4.14: Net Zero Scenario share of scrap in steel and aluminium, and clinker to cement ratio in cement production projections

In steel, scrap utilisation is projected to rise from 22% today to 30% by 2050, and reaching 40% by 2070, reducing reliance on energy-intensive ore-based smelting. In aluminium sector, recycling is projected to become dominant route of production, using just 5% of the energy required as compared with primary production. Cement is projected to lower clinker ratios and adopt blended cements with recycled aggregates, cutting both process and fuel emissions. Plastics and fertiliser are projected to shift toward mechanical and chemical recycling and precision nutrient application, reducing demand for virgin feedstocks (Figure 4.14).

Collectively, these interventions account for 6% of emissions reductions under the Net Zero Scenario compared to the Current Policy Scenario and reduce reliance on imported coking coal, and polymer feedstocks.

Transit-Oriented Development

By 2070, nearly two-thirds of Indians, an additional 800 million people, are expected to live in cities, making urban planning central to India's low-carbon future. Transit-Oriented Development (TOD), built around metro and rail stations with safe walking, cycling, and reliable last-mile options offer major co-benefits: reduced congestion, improved air quality, fewer road fatalities, and lower transport costs. When scaled across cities, TOD can help avoid millions of private vehicle purchases through high Floor Area Ratio (FAR) development near transit hubs, parking restrictions, and non-motorised street design.

India has strong institutional support: Smart Cities Mission, AMRUT, national TOD guidelines, Metro Rail Policy, and Mission LiFE, which can be strengthened through unified transport authorities and integrated mobility platforms. Early examples in Delhi, Ahmedabad, and Kochi show how proximity to quality transit and dependable last-mile connectivity shifts travel behaviour and shortens commutes.

Managing Residual Emissions through Carbon Capture Technologies

As shown in Figure 4.12, even after deploying all the above mentioned measures, the Net Zero Scenario will have residual emissions of about 1.3 $GtCO_2e$ by 2070. These will remain in certain hard-to-abate sectors by 2070: for example, methane and nitrous oxide from agriculture, some industrial process emissions, and fossil fuel use in aviation, shipping, and industry.

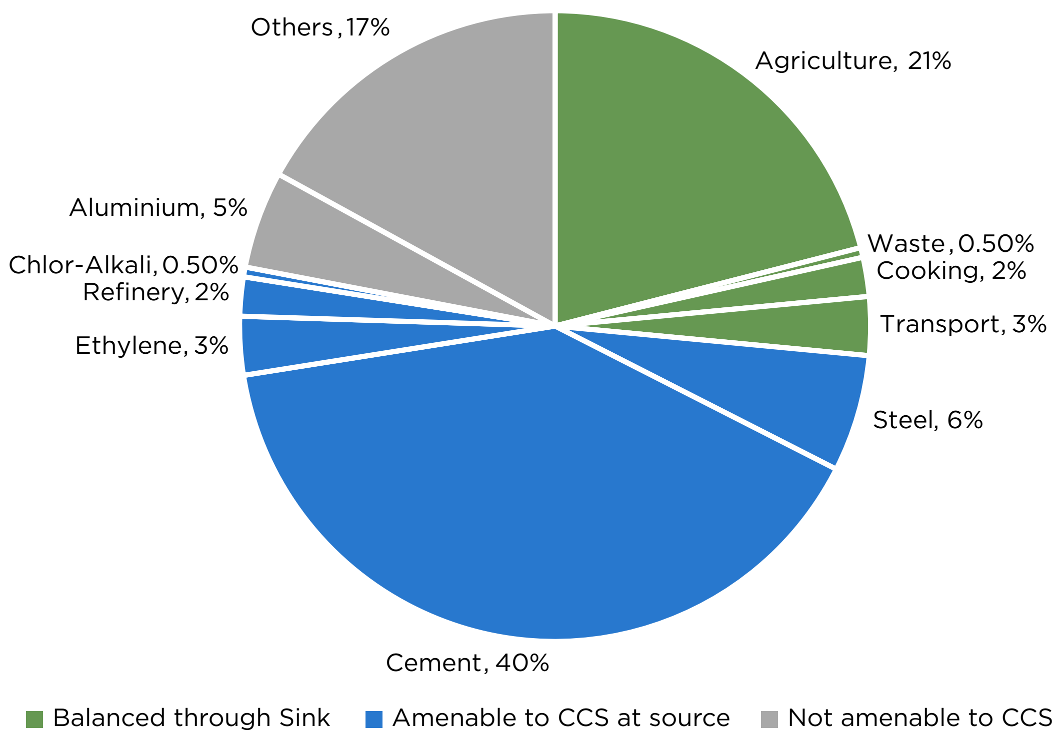


Figure 4.15: Projections of Residual emissions in Net Zero in 2070

Residual emissions will persist due to technological, behavioural, and economic barriers. In the aluminium industry, a key challenge is the absence of commercially viable inert anode technology, which is needed to eliminate potent perfluorocarbon (PFC) emissions from the anode effect.

In the cooking sector, behavioural barriers dominate, as long-standing cultural preferences and practices hinder wider adoption of clean electric cooking. In industry, major emissions stem from process emissions in high-energy sectors such as cement and petrochemicals. In other industrial segments, economic constraints prevail: small-scale, dispersed combustion units face limited grid and fuel access, capital shortages, and slow policy enforcement, making electrification difficult.

In the agriculture sector, sustainable farming practices and improved soil management deliver mitigation co-benefits, contributing to an estimated 2% reduction in overall GHG emissions in the Current Policy Scenario (CPS), while simultaneously strengthening food security and rural livelihoods. However, significant residual emissions from agriculture, around 21% of gross emissions under the Net Zero Scenario (NZS), remain by 2070. This reflects the sectors deliberate adaptation-first approach and recognises agriculture's central role on climate justice and inclusive growth. By scaling multi-benefit pathways, the sector balances limited near-term mitigation potential with long-term resilience and socio-economic sustainability.

These barriers mean that residual emissions will remain until technologies mature, costs decline, and practices evolve. Even by 2070, the Net Zero pathway anticipates around 1.3 $GtCO_2e$ of residual emissions annually, after accounting for the 0.5 $GtCO_2$ per year natural sink, emissions that are difficult to eliminate through behaviour or technology alone.

Point-source CCUS can be deployed in the cement (process CO_2 from calcination), steel, and refining/chemicals. Figure 4.16 underscores this distribution where capture volumes are concentrated in cement kilns, petrochemicals, and iron- and steel-making, reflecting areas where inherent process emissions persist even after technology shifts.

While two-thirds of residual emissions remain amenable to carbon capture and storage (CCS), the remainder currently lacks proven technological options and relies on Direct Air Capture (DAC) technologies that exist only in a few pilots globally and carry extremely high costs. CCUS requires additional power alongside CO_2 transport and storage infrastructure; planning therefore, must incorporate "capture-ready" designs into new hard-to-abate assets to ensure future retrofit flexibility.

5

SECTORAL TRANSITION PATHWAYS

Sectoral Transition Pathways

5

Following the comprehensive economy-wide analysis, this chapter turns to sector-specific pathways that will shape India's transition to Net Zero emissions. It examines each major sector: transport, buildings, industry, agriculture, and waste, through the lens of its distinct dynamics, including structural shifts, efficiency gains, technological advancements, and evolving energy mix. This chapter presents a clear picture of the incremental progress and transformative shifts envisioned under the Net Zero Scenario, offering insights into the targeted actions required to build a balanced, inclusive, and resilient low-carbon economy.

While this chapter provides a broad transition outlook across sectors, detailed sector-specific analyses are presented in separate reports for each sector, which together form a series under this Net Zero Pathways work.

5.1 POWER SECTOR

Electricity lies at the heart of India's transformation. Reliable, and affordable electricity will underpin progress in every sector of the energy economy, including industry, transport, agriculture, and services, while enabling a higher quality of life for citizens across both urban and rural India.

Against this backdrop, India's electricity generation landscape undergoes a profound transformation under both scenarios assessed. The analysis draws on two capacity-expansion models: (1) NITI's TIMES model and (2) CEA's ORDENA model, which are closely aligned in their core assumptions, including sectoral electricity demand, the portfolio of available generation technologies, and projected investment cost trends.

Detailed methodology and scenario assumptions for the power-sector low-carbon transition are documented in the Working Group Report on the Power Sector (Volume 7). This section focuses on the broad results, presenting the evolution of the capacity mix, generation mix, and per-capita electricity consumption.

5.1.1 Installed Capacity

India's power sector undergoes a major shift toward non-fossil sources: Figures 5.1 and 5.2, and Table 5.1 show the power generation installed capacity for Current Policy Scenario (CPS) and Net Zero Scenario (NZS) respectively. Each figure has results for both 2050 and 2070 using the output of NITI (TIMES) model and CEA (ORDENA) model. By 2050, non-fossil capacity is projected to reach 89% under the NZS and 81-83% under CPS. By 2070, this increases further to 98% in NZS and 94-95% in CPS (see Figures 5.1 and 5.2). It is noteworthy that even in CPS, there is significant uptake of non-fossil sources. This reflects existing policy momentum and growing competitiveness of renewables.

However, this shift must be viewed in context. As mentioned in the previous section, electricity demand in 2070 under Net Zero Scenario (NZS) is 34% higher than that under Current Policy Scenario (CPS). As a result, similar percentage shares mask a significant difference in absolute clean energy deployment, NZS requires a much larger non-fossil base to meet deeper electrification and low-carbon growth goals.

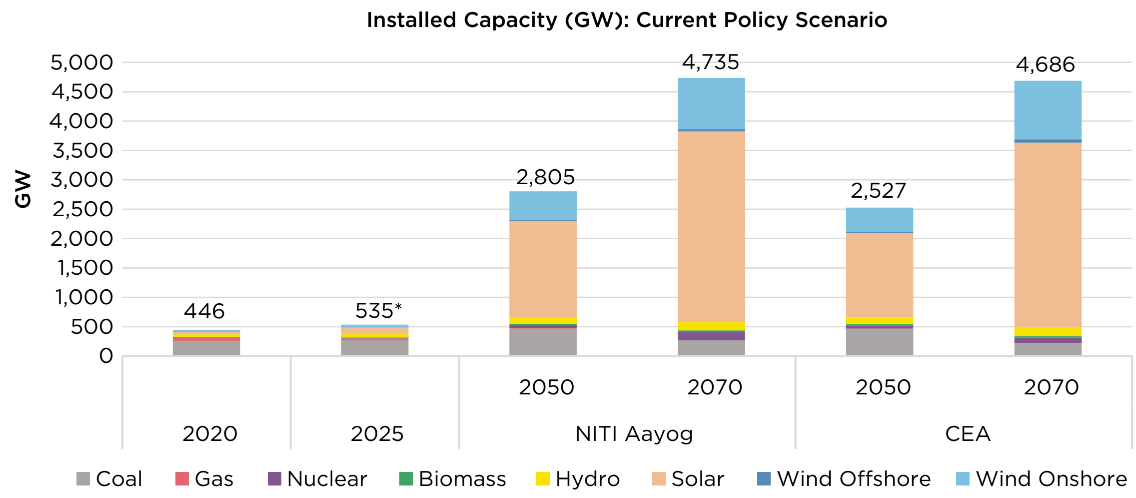


Figure 5.1: Projected electricity generation capacity for 2050 and 2070 in Current Policy Scenario (CPS)

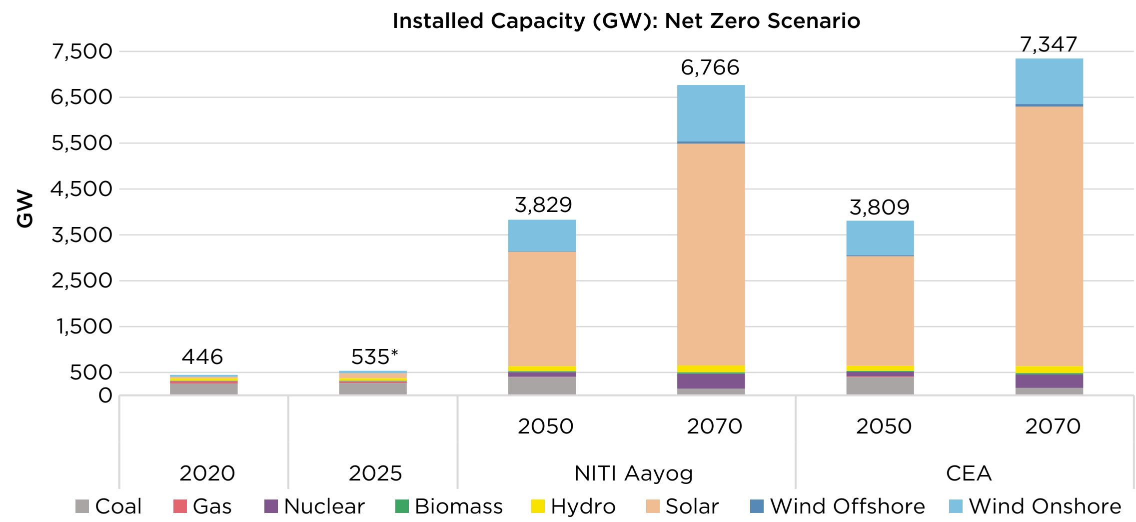


Figure 5.2: Projected electricity generation capacity for 2050 and 2070 in Net Zero Scenario (NZS)

**In case of total installed capacity of 2025, captive installed capacity is estimated. Utility based generation for 2025 is India Climate & Energy Dashboard.*

Table 5.1: Capacity mix across two models in Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

	2020	2025	2050		2070	
			CPS	NZS	CPS	NZS
Coal	58%	50%	17%-18%	10%	5%-6%	2%
Gas	10%	6%	0%-1%	0%	0%	0%
Nuclear	2%	2%	2%	3%	2%-3%	4%-5%
Biomass	2%	2%	1%	1%	1%	1%
Hydro	11%	10%	4%	3%	3%	2%
Solar	8%	21%	57%-59%	63%-65%	67%-69%	72%-77%
Wind	9%	10%	16%-17%	18%-21%	17%-22%	15%-18%

RE and Storage: New Core of the Grid

In the Current Policy Scenario (CPS), RE capacity is projected to increase from 229 GW in 2025 to around 4400 GW by 2050 and 6300-6900 GW in the Net Zero Scenario (NZS) by 2070. As variable renewables dominate the capacity mix, Battery Energy Storage Systems (BESS) shift from being peripheral assets to be core grid infrastructure. BESS capacity is expected to surge to 2,500-3,000 GW by 2070 under NZS. Even CPS sees significant growth in BESS capacity reaching 1,300–1,400 GW by 2070. In parallel, pumped hydro storage capacity is projected to expand to 150–165 GW in NZS Vs 110 GW in the CPS by 2070, providing multi-hour to multi-day firmness and reducing renewable curtailment.

Coal-Plan New Units for Initial Years Base-load

While coal plants remain important for adequacy and flexibility in the near-to-medium term, their role diverges across scenarios. Coal capacity is projected to rise from 268 GW in 2025 to around 450-470 GW in CPS, and to 400 GW in NZS by 2050. The capacity in subsequent decades is projected to decline due to substantial non-fossil capacity addition in both the scenarios.

This shift underscores the need to review new coal investments. Any upcoming plants must be designed for deep turndown, fast ramping, low minimum loads, and cycling capability.

Nuclear Power's Scale-up is Crucial

Nuclear power is crucial to achieving long term goals of power sector decrabonisation. It provides firm, low-carbon power, high-temperature heat, and electrolyzer backing for green hydrogen. Nuclear power is projected to grow from the present 8.18 GW in 2025 to 295–320 GW by 2070 under NZS; an increase of 36 to 39 times. Even CPS envisions 90–135 GW; an increase of 10 to 15 times. The earlier and larger buildout under the Net Zero Scenario better matches the flexibility and reliability needs of a renewables-dominant grid.

Box 5.1: There could be multiple pathways to achieve Net Zero in the power sector.

One scenario retains a sizeable coal fleet in the generation mix even in 2070. However, realising full power sector decarbonisation in such a pathway would hinge on large-scale deployment of carbon capture, utilisation, and storage (CCUS) technologies on coal plants. This situation becomes relevant if the growth of renewable energy (RE) and nuclear power is slower than anticipated, owing to high capital costs of nuclear, challenges in land acquisition, environmental clearances, grid integration constraints, supply chain bottlenecks, or delays in nuclear project development and public acceptance. In this coal-plus-CCUS pathway, firm coal capacity partially substitutes for long-duration storage, reducing the BESS requirement significantly.

Another scenario is where the rise in nuclear capacity remains limited, which would necessitate even higher RE capacity, especially solar, surpassing 5,500 GW. This pathway, however, would further increase the requirement for energy storage capacity to ensure reliability and flexibility of the grid.

Achieving Net Zero depends on the complementary roles of RE paired with storage, delivering scalable flexible power; and nuclear, providing firm, low-carbon generation, together with the pace at which both are deployed.

5.1.2 Electricity Generation

India's power system is expected to scale to multi-petawatt-hour output while its fuel mix is projected to shift from coal-led to renewables-led (see Figures 5.3 and 5.4). Both modelling streams (CEA and NITI) show the same trajectory: in the Current Policy Scenario (CPS), gross generation grows from ~2,000 TWh (2025) to 7,350–7,700 TWh (2050) and ~11,100 TWh (2070). The Net Zero pathway has higher generation due to higher electrification; 9,700–10,200 TWh in 2050 and ~16,000 TWh in 2070.

The RE share in generation is projected to increase from 20% in 2024-25 to over 80% in the CPS and over 85% in the Net Zero Scenario (NZS) by 2070, reflecting the dominance of renewables in future electricity generation, supported by a large increase in the capacity of energy storage systems.

Further, the contribution of nuclear power increases many fold, from 3% to 13-14% in NZS vs 5-8% in CPS by 2070, reflecting its growing role in displacing coal-based generation and providing carbon-free baseload power. Lastly, coal's share in overall electricity generation is projected to remain 6-10% by 2070 in CPS, while in NZS, there is limited generation from coal capacity. A significant coal capacity in NZS (~140-160 GW) may be reserve capacity rather than actively generating.

Box 5.2: Enabling legislative framework for Nuclear Power

Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Act, which repeals existing legislations (Atomic Energy Act, 1962 and Civil Liability for Nuclear Damage Act, 2010) and provides a comprehensive legal framework aligned with India's current and future energy needs, is significant. It allows private/PSU entities to build-own-operate-decommission plants and participate in the fuel value chain.

While both scenarios see a significant decline in coal capacities, PLF during the intermediate period, hovers around 62-65% indicating partial load operation.

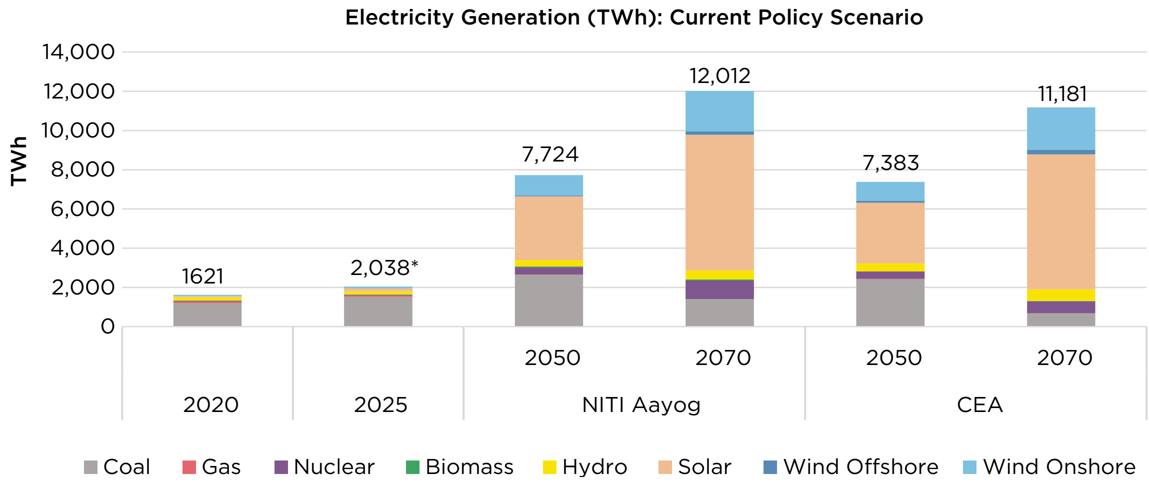


Figure 5.3: Projected electricity generation mix for 2050 and 2070 in Current Policy Scenario (CPS) using NITI (TIMES model) and CEA (ORDENA model)

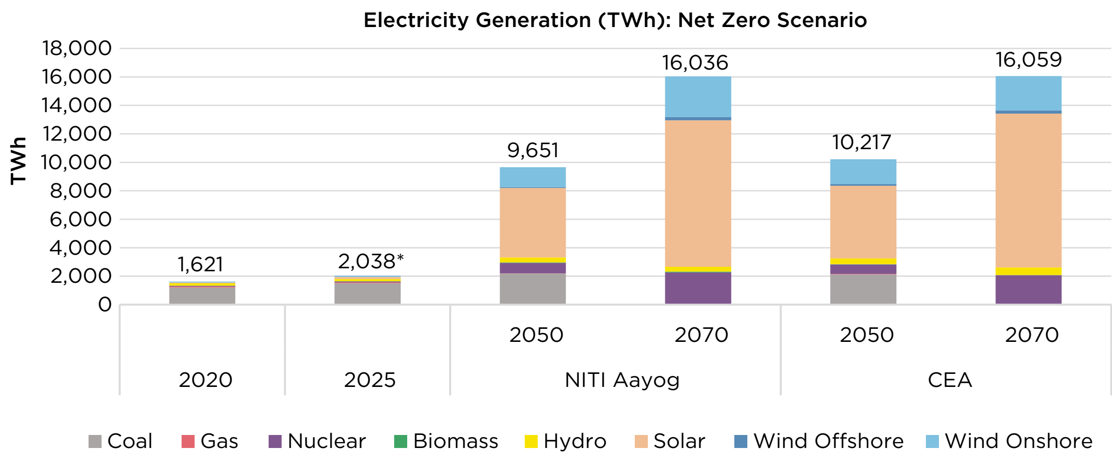


Figure 5.4: Projected electricity generation mix for 2050 and 2070 in Net Zero Scenario (NZS) using NITI (TIMES model) and CEA (ORDENA model)

**In case of total generation of 2025, captive generation is estimated. Utility based generation for 2025 is India Climate & Energy Dashboard.*

Table 5.2: Generation mix across two models in Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

	2020	2025	2050		2070	
			CPS	NZS	CPS	NZS
Coal	74%	74%	33%-34%	21%-23%	6%-12%	0%
Gas	5%	3%	0%	0%	0%	0%
Nuclear	3%	3%	5%	7%-8%	5%-8%	13%-14%
Biomass	1%	1%	0.4%	0.4%	0.4%	0.3%
Hydro	10%	8%	4%-6%	4%	4%-5%	2%-3%
Solar	3%	7%	42%	50%-51%	58%-62%	64%-67%
Wind	4%	4%	14%	15%-18%	18%-21%	16%-19%

Three system insights follow:

- Coal power is expected to shift from energy generation to insurance against shortages (capacity/availability matters more)
- Energy storage systems convert variability into value by absorbing mid-day solar and curbing curtailment (so part of the higher Net Zero TWh is the cost of flexibility that enables near-zero-carbon supply)
- Planning focus migrates from adding thermal megawatts to orchestrating solar-wind-storage-nuclear-hydro portfolios with stronger transmission and time-of-day price signals.

5.1.3 Per-capita Electricity Consumption

India's per-capita electricity consumption is projected to rise from a relatively low base. At roughly 1,400 kWh/person in FY2023–24, the country remains in the early stages of demand compared with OECD economies and nations that achieved similar income levels earlier. This underscores the significant untapped demand across productive, social, and household uses as incomes rise, services expand, and electrification accelerates. With substantial headroom for electricity-driven growth in households, urban services, MSMEs, industry, and clean mobility, India's power system can be strategically planned to accommodate this long-term expansion.

As shown in Figure 5.5, under Current Policy Scenario (CPS), per-capita electricity use is projected to reach about 4,600 kWh/person by 2050. Under Net Zero Scenario (NZS), the same indicator rises to around 6,000 kWh/person, because of greater electrification of cooking, road transport (EVs), and industrial processes to replace fossil fuels. By 2070, CPS trajectory rise further to about 6,900 kWh/person, while NZS outcomes reach around 9,900 kWh/person, even as there are continued improvements in energy intensity and active demand-side management.

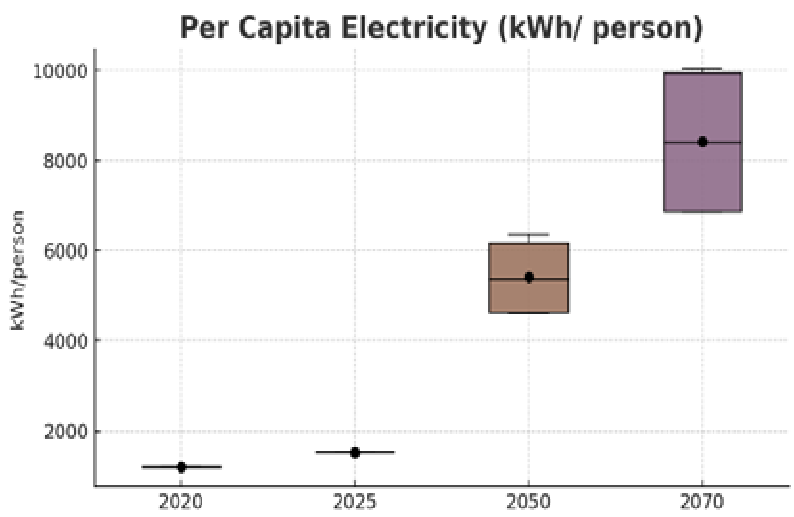


Figure 5.5: Per-capita electricity consumption in different scenarios

5.1.4 Challenges and Suggestions

The power sector is the backbone of India's development and is also crucial for achieving India's Net Zero ambitions. Reliable, affordable, and clean electricity is essential for industrial growth, and quality of life. India has expanded electricity access and scaled renewables rapidly, but coal still supplies ~75% of generation, and Distribution Companies (DISCOMs) face persistent financial stress. Large scale integration of variable renewables remains a challenge.

1. Generation

Challenge: India's grid is dependent on coal. A long-term expansion of clean and flexible resources requires effective grid management. Variable renewable energy exposes the system to intermittency; long duration energy storage and nuclear have yet not scaled.

Suggestions:

i. **Scale nuclear power to 100 GW by 2047 and 200-300 GW by 2070**, including advanced reactors and Small Modular Reactors (SMRs) to provide reliable 24×7 clean supply. Delivering this requires:

- **Nuclear Captive Shift:** Industrial and large captive consumers may be encouraged to transition from coal-based captive power plants to Small Modular Reactors (SMR), enabling cleaner baseload generation. This shift would support national low-carbon transition goals while maximising the use of existing land, transmission connectivity, and industrial infrastructure.
- **Develop and implement the Nuclear Energy Mission** to deliver the 100 GW roadmap by 2047. This requires addressing several issues such as long gestation and ecosystem constraints through fast-tracking approvals, enabling site readiness and pre-project development, ensuring assured offtake (including DISCOM procurement frameworks). It also needs commensurate fuel supply augmentation, scaling domestic manufacturing/EPC capacity with an assured order book,

expanding workforce and certified training capacity, and strengthening insurance capacity for a multi-operator market.

- **Accelerate indigenous Small Modular Reactor (SMRs):** Accelerate development and deploy SMRs with private participation in industries.

ii. **Scale up co-located solar–wind hybrids with storage** to improve land-use efficiency, transmission and distribution system efficiency, reduce curtailment, and deliver a firmer clean supply. Key reforms include:

- Ministry of New and Renewable Energy (MNRE) in coordination with state nodal agencies, should identify priority hybrid zones, facilitate land aggregation, and streamline single-window clearances.
- SECI and State Discoms may issue coordinated tenders supported by standardised PPAs and robust payment security mechanisms.

iii. **Promote Distributed Energy Resources (DERs):** India may prioritise decentralised solar as a core DER to meet the Viksit Bharat 2047 and net-zero objectives. This approach can reduce land pressures, T&D losses, and system vulnerabilities arising from geographic concentration of generation. As land is likely to remain a binding constraint, given its competing uses for livelihoods, grazing, and biodiversity, policy should also emphasise land-neutral solutions such as agrivoltaics, floating solar, rooftop solar and building-integrated PV, supported through operational VGF:

- Develop and operationalize Viability Gap Funding for promotion of land-neutral solar solutions such as Agri-PV, Floating Solar and Building Integrated PV
- MNRE, in collaboration with state DISCOMs, may expand Renewable Energy Service Company (RESCO) and utility-led aggregation models under PM Surya Ghar and PM-KUSUM through standardised guidelines, bankable contracts, and robust payment security mechanisms.
- DERs, including community solar paired with decentralised storage, may be formally integrated into distribution planning and resource adequacy frameworks, enabled through regulatory mechanisms such as virtual or group net metering and subscription-based models.

iv. **Improve Flexibility of Existing Thermal Fleets:** To integrate higher shares of VRE, coal based power plants must operate more flexibly under a clearly defined framework for flexible coal operation. This should include norms for Minimum Technical Load (MTL),

- CEA, in collaboration with relevant agencies may implement and monitor a phased flexibility programme to progressively achieve deeper minimum-load operation.
- To incentivise flexible operation, CERC/SERCs need to operationalise and extend compensation frameworks for flexible operation and enable market-based monetisation of flexibility.
- Identify old inefficient units for retirement, and repurpose these sites for captive nuclear and RE+Storage leveraging existing land, water and transmission infrastructure.

v. **Set national storage targets and procure at scale (across technologies):** Establish clear national targets for storage deployment across BESS, pumped storage and emerging long-duration options. Accelerate deployment through a predictable tender pipeline (standalone and RE and storage). This entails:

- Notifying technology-wise storage targets/trajectory (GW/GWh) and integrateing into national/state resource and transmission planning.
- SECI and State DISCOMs to roll-out tenders and enforce qualification/realisation safeguards to avoid "race-to-the-bottom" bids

vi. **Repower ageing wind/solar to add generation without new land/transmission:** Repower old RE assets with higher-efficiency equipment to raise output using existing sites and evacuation, minimizing incremental land and grid buildout.

- MNRE in collaboration with State DISCOMs identify potential repowering assets.
- State DISCOMs in partnership with project owners to identify repowering-friendly Power Purchase Agreement (PPA) pathways and incentivise incremental energy through clear metering/settlement for uprated capacity.

vii. **Develop and implement a Viability Gap Funding scheme** to accelerate emerging technologies such as Concentrated Solar Power (CSP) projects, long duration energy storage, advanced solar/wind designs (e.g., higher-efficiency modules, higher hub-height turbines), and other promising technologies with support linked to independently verified performance. The VGF framework should be technology-agnostic and targeted toward projects that demonstrate strong potential for cost reduction, grid stability, and domestic value creation.

2. Transmission and Distribution

Challenge: Renewable energy is often generated far from load centres, requiring long distance transmission. Often, there are delays in building transmission lines leading to curtailment risks. The mounting debt and losses of DISCOMS are a cause of concern, which limits investment. Local grids were not designed for rooftop solar injections, bi-directional flows, or new loads like EV charging. Digitisation has lagged behind targets, and only ~20% of approved smart meters had been installed.

Suggestions:

i. **Improving the financial viability of DISCOMs:** Ministry of Power (MoP) may consider designing a one-time DISCOM debt takeover and structuring scheme, with central support provided on a conditional basis. DISCOMs may also explore additional revenue streams by monetising non core assets, such as leasing unused land and increasing participation in non-PPA power markets.

ii. **Enable Competition and Active System Management in Distribution:** This will require amendments to the Electricity Act, to allow multiple distribution. to supply consumers over the incumbent utility's network through mandatory, non-discriminatory open access. In parallel, the introduction of Distribution System Operators (DSOs) for real-time management of the distribution network may be considered for actively managing the low-voltage networks, integrating distributed energy resources, including virtual storage such as smart loads and vehicle-to-grid systems.

iii. **Enable End-to-End digitalization of the grid**: To meet the growing power demand and enable large-scale renewable integration, India must accelerate the digitalisation of its grid. This includes upgrading existing infrastructure with real-time monitoring systems, automating substation operations, and adopting centralised control through Supervisory Control and Data Acquisition (SCADA) and remote monitoring tools.

- Utilities should implement predictive maintenance using AI-based tools, develop grid "digital twins" to simulate network behaviour, strengthen cybersecurity protocols, and train personnel in digital operations. Deploy distribution digital twins (live network replicas) to improve planning, loss reduction and reliability at scale, building on pilots such as the Global Energy Alliance for People and Planet (GEAPP)/International Solar Alliance (ISA) Rajasthan digital twin.
- Operationalise United Energy Interface (UEI) at scale by mandating interoperable APIs and consent-based data sharing, enabling portable consumer switching, and implementing dynamic tariffs and standard protocols for demand response and prosumer settlement.

iv. **Feeder Separation for 24x7 Reliable and Quality Power Supply**: To ensure all consumer categories receive, high quality reliable electricity supply, feeder segregation is critical. Each state may therefore adopt a feeder-segregation model best suited to its network conditions and consumer mix, guided by rigorous cost-benefit analysis and implemented within a clearly defined time frame.

v. **Strengthen Cross-Border Transmission Networks**: Strengthen and expand interconnections with neighbouring countries like Nepal, Bhutan and Sri Lanka to import/ export low-cost hydropower, export surplus solar/wind, and improve seasonal and diurnal balancing, enhancing reliability and reducing system costs.

3. Cross Cuttting Issues

Challenges: India's clean energy transition faces several interlinked challenges:

i. **Domestic manufacturing gaps:** Limited manufacturing depth for solar, wind, batteries, and electrolyzers, increasing import dependence and vulnerability to cost and geopolitical shocks. End -of-life waste streams from solar PV and batteries will grow rapidly. In the absence of adequate recycling, this will create environmental risks.

ii. **Cybersecurity risks:** Growing digitalisation needs robust protocols, to reduce exposure to cyberattacks and operational disruptions.

iii. **Low R&D investment:** limits innovation in emerging technologies such as storage, hydrogen, digital grid solutions, and advanced chemistries.

iv. **Planning and land bottlenecks:** Fragmented planning, slow clearances, and land disputes delay RE and transmission projects; renewable energy zones and corridors are not pre-identified; land records remain inadequately digitised.

v. **Workforce gaps:** Coal-dependent regions risk job losses; skilling programmes are fragmented and misaligned.

Suggestions:

(i) **Strengthen domestic manufacturing & circularity:** Reduce import dependence and geopolitical risks by building depth across solar, wind, storage and electrolyzer manufacturing, while closing the loop on PV and battery end-of-life to recover critical materials.

- Expand PLI scheme to cover inverters, and critical equipment beyond solar cell-to-module manufacturing.
- Operationalise traceability and recycling standards for PV and batteries (under updated waste rules) to create an assured feedstock pipeline for recyclers.
- Develop a Production Linked Incentives (PLI)/Output Linked Incentive (OLI) framework that rewards production of high-purity refined and recovered materials. Further, VGF may also be designed to catalyse large scale recycling facilities.

(ii) **Mandatory Cyber-Security framework for Power Sector:** CEA, in coordination with designated Government Agencies such as CERT-In & NCIIPC may mandate a uniform minimum cybersecurity framework for utilities, grid operators and critical power infrastructure. This framework should cover inter alia, regular third-party security audits, incident reporting protocols, network segmentation, access controls, and supply-chain security for both hardware and software.

(iii) **Strengthen R&D & innovation ecosystem** by scaling private investment in clean energy R&D, establish dedicated centres in leading institutes. Incentivise industry-academia partnerships, and support innovation in storage, hydrogen, digital grid solutions, and demand-side management. Expand clean-tech incubators and global collaborations (e.g., Mission Innovation).

(iv) **Enhance policy stability and investor confidence** by publishing long-term, predictable roadmaps for tariffs, auction designs, and manufacturing support to avoid abrupt shifts. A stable and transparent regulatory environment is essential to attract both domestic and global capital at scale. Key measures include:

- **Shift beyond PPAs** to flexible market design expanding short-term market, capacity market, and ancillary service markets that reward flexibility and reliability.
- **Strengthen open access rules** so that large consumers can procure renewable power directly and competitively.
- **Scaling out Time-of-Day (ToD) and Time-of-Use (ToU) tariffs** nationwide, supported by smart meters and the Unified Energy Interface (UEI).
- **Strengthen institutional and regulatory capacity** by increasing staffing and budgets of State Electricity Regulatory Commissions (SERCs) and DISCOMs to manage renewable integration, efficiency enforcement, and new technologies.
- **Improve planning and land processes** through pre-identification of Renewable Energy Zones (REZs) and transmission corridors, cumulative impact assessments,

digitised land records, and single-window clearances with strict timelines, clear compensation and early stakeholder engagement.

- **Continuous training for regulators** and grid operators on forecasting, flexibility, digitalisation, and cybersecurity.

(v) **Skilling and reskilling the workforce** by aligning national programmes such as Skill India, PM-KUSUM, and PM Vishwakarma, with emerging clean energy industries. Reskill coal and thermal power workers for renewable, storage, and grid-service roles. Expand vocational training and certification for installers, O&M technicians, and digital grid specialists.

5.2 TRANSPORT

The transport sector plays a critical role in energy transition, given its strong linkage with economic growth, urbanisation, and mobility demand, as well as its historically high dependence on fossil fuels. Accordingly, a detailed representation of transport activity, modal structure, and technology choice is essential for assessing long-term low-carbon growth pathways.

Transport activity is projected in billion passenger-kilometres (BPKM) for passenger transport and billion tonne-kilometres (BTKM) for freight. The projections of these transport activity demands are driven by macroeconomic growth, using a saturation-based model where transport demand increases with per capita GDP until it saturates, as discussed in Chapter 3. The total activity is allocated across transport modes: Road, Rail, Metro, and Air for passengers, and Road, Rail, Air, Water, and Pipelines for freight, then further segmented by vehicle type and fuel/technology.

For a complete methodology and detailed scenario assumptions related to the transport sector energy transition, the Working Group Report on the Transport Sector (Volume 3) may be referred to. However, the broad results on modal shift, final energy consumption, and fuel mix are presented here.

5.2.1 Modal Shift

India's transport demand remains overwhelmingly road-centric. In 2023, road transport accounted for 78% of passenger movement, followed by rail (17%), air (4%), and metro (1%). Freight transport shows a similar pattern: 67% is moved by road, 22% by rail, 8% by waterways, 4% by pipelines, while air transport remains negligible. These figures highlight India's heavy dependence on road networks, with rail serving as a strong but secondary mode. Meanwhile, metro systems in cities and inland waterways for freight remain underutilised, despite their potential to ease congestion, cut costs, and reduce emissions.

Modal Shift in Passenger Transport

Road dominance persists but declines steadily: India's passenger transport system is projected to undergo a gradual modal shift by 2070, as shown in Figure 5.6. Road transport's share is projected to fall to 70% under Current Policy Scenario (CPS) and 64% under Net Zero Scenario (NZS) driven by the expansion of rail, metro, and aviation, while remaining the dominant mode of passenger transport.

Rail emerges as a low-emission backbone: Rail's expansion is supported by plans to double the network by 2047 and major efficiency upgrades. This is expected to push passenger volume up from 6.9 billion in 2024 to 19.2 billion by 2051 (NRP). Under NZS, rail's share rises to 25% by 2070 compared with 20% under CPS, positioning it as the primary low-carbon option for medium- and long-distance travel.

Urban metro systems scale rapidly: Metro and rapid transit networks are expected to grow from about 1,000 km in 2025 to 3,600 km under Current Policy Scenario (CPS) and 5,000 km under Net Zero Scenario (NZS) by 2047. While the CPS represents a gradual rebalancing, the NZS delivers a deeper structural shift towards efficient, low-emission urban mobility, mirroring progress in Japan and Europe.

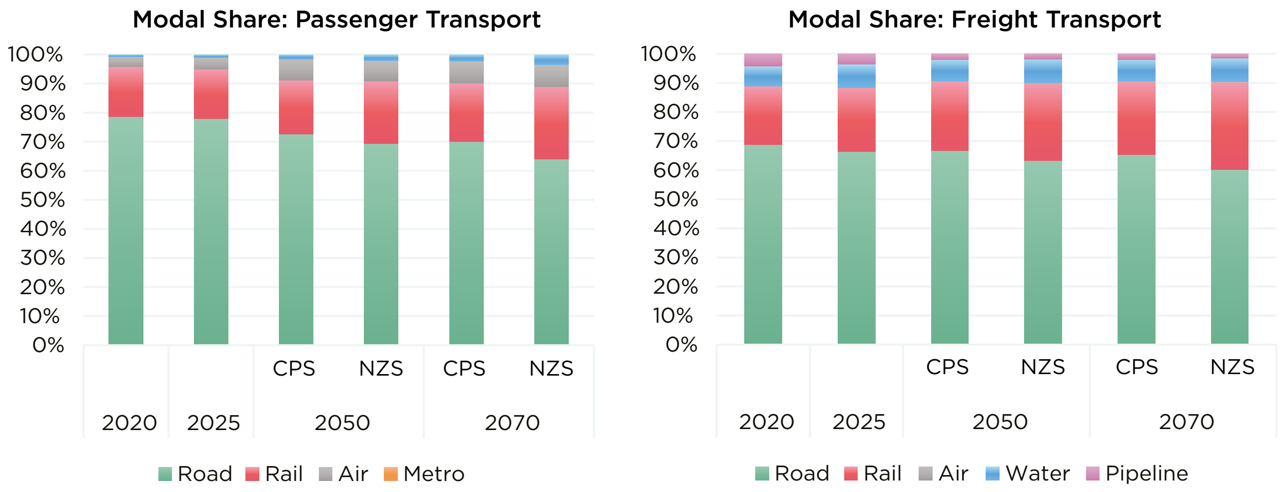


Figure 5.6: Projections of modal share in transport-passenger and freight under Current Policy Scenario (CPS) and Net Zero Scenario (NZS) for 2050 and 2070

Shift towards public transport accelerates: In 2023, 53% of passenger road usage is private and 47% public. By 2070, this shifts to 50% public under the CPS and 60% under the NZS by 2070, driven by initiatives such as PM-eBus Sewa (10,000 e-buses in 100 cities), state-led mobility programs, and investments in digital ticketing, first/last-mile connectivity, and shared mobility, enhancing accessibility and affordability.

Personal Vehicular Ownership

India's vehicle fleet is dominated by two-wheelers, followed by cars, reflecting affordability-driven mobility. Trends show a gradual shift toward four-wheelers and shared mobility as incomes rise. Vehicle ownership is expected to grow sharply by 2070, intensifying urban congestion. India's private vehicle ownership stood at 197 per 1,000 people in 2023 (167 two-wheelers, 30 cars). By 2070, car ownership is projected at 250 per 1,000 under CPS and 200 under NZS. It is reinforcing the shift toward public transit, shared mobility, and compact urban development.

Modal Shift in Freight Transport

India's freight mix evolves differently under the Current Policy and Net Zero scenarios. Road freight is projected to remain dominant but declines to 65% by 2070 under Current Policy Scenario (CPS), and 60% under Net Zero Scenario (NZS). Rail and waterways are likely to expand through policy support and infrastructure investment. Waterways, boosted by the Maritime Amrit Kaal Vision 2047, are likely to quadruple cargo handling by 2047, reaching 7-8% share. Overall, CPS delivers incremental modal shifts, while NZS achieves a more transformative rebalancing, with rail and waterways gaining prominence.

Within these modal shares, transport energy demand is estimated using a bottom-up ASIF framework, which decomposes energy use into four components: Activity (A), Share (S), Intensity (I), and Fuel (F). Energy demand is derived by multiplying travel activity with the energy intensity (or mileage) of each vehicle technology under each category.

5.2.2 Transport Sector Electrification

Rising energy demand, declining battery costs, and the need to cut transport emissions are driving rapid electrification of India's transport sector, with adoption rates varying across vehicle types and scenarios. This study projects that two-wheelers (2Ws) and three-wheelers (3Ws) will lead the transition due to smaller batteries and faster total cost-of-ownership parity, while four-wheelers, buses, and commercial vehicles adopt EVs more slowly owing to higher upfront costs and larger battery requirements. Barriers such as limited charging networks, expensive financing, and supply chain constraints need to be addressed.

5.2.3 Final Energy Consumption

In 2025, India's transport sector consumed 137 Mtoe of energy, with average intensities of 483 kJ/pkm and 585 kJ/tkm[i] in passenger and freight, respectively. This also aligns with the global average intensities at 500-600kJ/pkm in passenger transport and 500-700/tkm in freight transport. Figure 5.7 show the projections on fuel wise energy consumption for passenger and freight transport under different scenarios.

Under both scenarios, final energy consumption initially increases and subsequently declines by 2070. Total energy consumption in Current Policy Scenario (CPS) vs Net Zero Scenario (NZS) (including both passenger and freight) is at 307 Mtoe vs. 192 Mtoe in 2070 (lower by 37%). This trend is primarily driven by the rising share of electric vehicles in the overall vehicle stock, which leads to lower energy consumption due to the higher energy efficiency of EVs. In addition, the lower transport energy use under NZS is a result of multiple factors: reduced transport demand driven by Transit-Oriented Development (TOD), modal shift from road to rail, increased share of public transport, fuel efficiency, and technology shift, as shown in Figure 5.8.

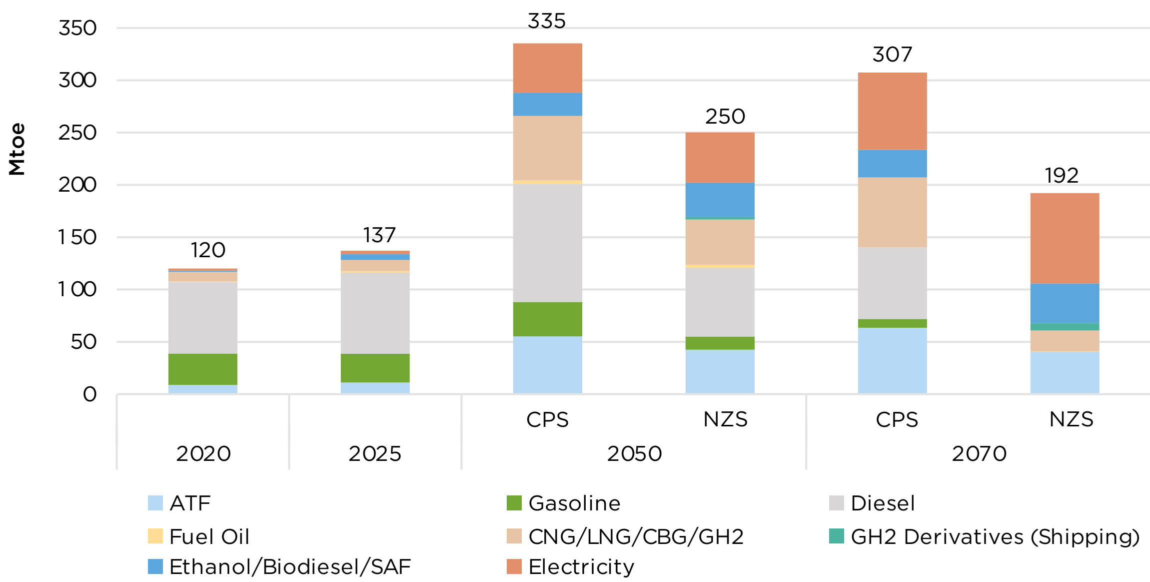


Figure 5.7: Fuel consumption in transport sector for 2050 and 2070 under Current Policy Scenario (CPS) and Net Zero Scenario (NZS), Million tonne of oil equivalent (Mtoe)

i kj/ pkm - kilojoules per passenger kilometre travelled; kj/tkm - kilojoules per tonne kilometre of freight

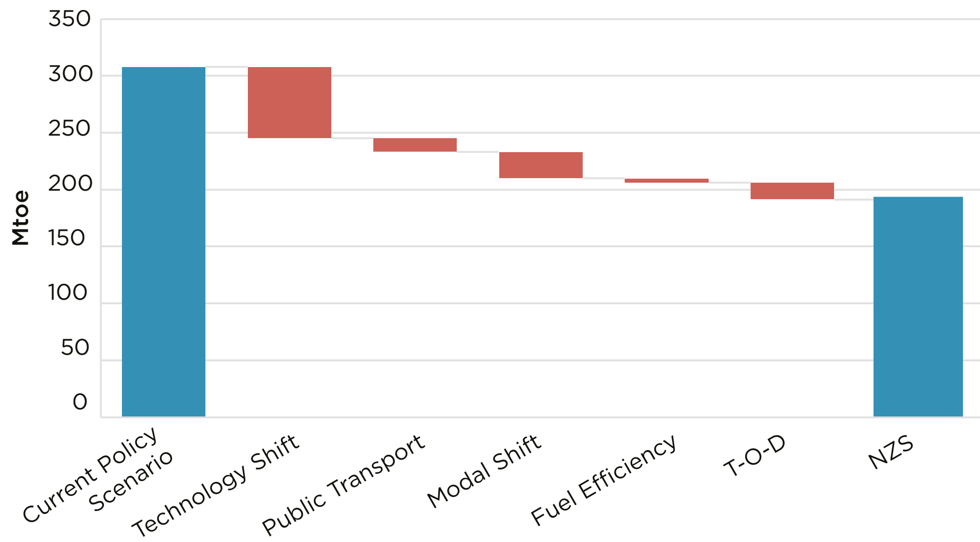


Figure 5.8: Drivers of lower energy use in Net Zero Scenario (NZS) by 2070

Fuel Mix: Currently, nearly 96% of India's transport energy demand is met by petroleum products and gas, as depicted in Figure 5.7. Under Current Policy Scenario (CPS), the sector remains predominantly fossil-based, with over three-quarters of supply fossil based in 2050 and 64% by 2070. In contrast, the Net Zero Scenario (NZS) triggers a shift toward low-carbon carriers: by 2050, electricity, biofuels, and hydrogen are collectively projected to reach almost half of the transport energy mix, increasing to nearly 90% by 2070. Petroleum products are almost entirely phased out from road transport, leaving aviation turbine fuel (ATF) as the primary residual fossil fuel, reflecting the challenges of aviation decarbonisation. Relative to the Current Policy Scenario (CPS), the Net Zero Scenario (NZS) is projected to reduce fossil fuel consumption by 176 Mtoe in 2050, lowering exposure to price volatility and enhancing macroeconomic resilience.

Role of Natural Gas: Natural gas offers a vital short to medium-term bridge for India's transport low-carbon growth, but long-term success depends on a decisive shift to zero-emission technologies. CNG and LNG are expected to grow steadily until 2050, serving as an effective bridge fuel for urban buses, taxis, and high-mileage freight fleets. This growth helps cut local air pollution and reduce costs while the ecosystems for electric and hydrogen-based mobility scale up.

The long-term trajectory of natural gas in transport diverges depending on policy choices. Under Current Policy Scenario (CPS), gas demand continues to rise, potentially reaching 65 Mtoe by 2070. By contrast, under Net Zero Scenario (NZS), natural gas consumption in transport peaks at about 32 Mtoe around 2045, plateaus briefly, and then got substituted by Bio-CNG utilising existing infrastucture along with other gaseous fuel including Green Hydrogen.

Role of Biofuels: India's commitment to ethanol-based technologies and advanced biofuels is steadily gaining momentum, fuelled by the need to reduce oil imports and diversifying the mobility energy mix. The achievement of 20% ethanol blending by mid-2025 (five years ahead of its original timeline) illustrates India's capacity to scale policy-driven clean energy solutions and build robust supply chains.

However, under CPS, biofuels remain primarily focused on road transport: ethanol is projected to peak at about ~21 billion litres in the mid-2040s before slightly decreasing through 2070, Sustainable Aviation Fuel penetration remains modest under CPS.

In contrast, under NZS, biofuels scale over time. Ethanol is projected to reach around 11 Mtoe (~22 billion litres) by mid-century, and then plateau thereafter through higher adoption of flex-fuel vehicles that can operate on higher ethanol blends (E20–E85/E100). SAF becomes the primary growth engine, scaling up to 32 billion litres by 2070. Together, they reinforce India's goals of energy security, industrial competitiveness, and deep decarbonisation in the transport sector.

As electrification accelerates, flex-fuel hybrids and advanced biofuels (CBG, FFVs) will continue to play a vital role as enablers of a diversified and resilient clean mobility transition.

Role of Green Hydrogen: India is advancing hydrogen and fuel cell technologies as part of its long-term clean mobility strategy. Under Net Zero Scenario, hydrogen fuel cell vehicles (HFCVs) complement battery EVs from 2035, especially in segments where electrification faces limits. HFCVs are projected to consume ~2 million tons by 2050 and ~5 million tons by 2070, with buses and heavy trucks accounting for up to 20% of sales, providing low-emission solutions for long-range, high-utilisation transport.

Additionally, green hydrogen derivatives (consumed in shipping sector) including e-methanol and green ammonia reaches 2.4 Mtoe and 7.1 Mtoe, respectively. This pathway aligns with global perspectives that long-haul trucking, shipping (via ammonia), and synthetic fuels will be demand centres for green hydrogen. Unlocking this potential will require large-scale electrolyser deployment and dedicated renewable energy capacity.

India's transport transition will hinge on modal shifts, energy efficiency, technology adoption, and fuel diversification. Under Current Policy Scenario, progress is gradual, with road transport and fossil fuels remaining dominant. In contrast, Net Zero Scenairo charts a transformative path–expanding rail and public transport, accelerating EV adoption (led by 2Ws and 3Ws to start and expanding to all segments later), promoting biofuels through flex-fuel and Bio-CNG based vehicles, and advancing green hydrogen for heavy-duty segments. Shipping and aviation also evolve, with ports adopting shore power and green fuels (e-methanol, ammonia) and aviation scaling SAF. Together, these shifts reduce fossil fuel dependence, curb emissions, and strengthen energy security, aligning India's transport system with a low-carbon, high-efficiency future.

5.2.4 Challenges and Suggestions

A comprehensive avoid-shift-improve strategy is needed to decarbonise transport while enhancing accessibility, affordability, and safety.

1. Integrated Urban Mobility and Safety

Challenges: Passenger transport is dominated by road (78% in 2025), while metro and rail contribution is modest. Rising private vehicle ownership worsens congestion. The declining share of public and non-motorised transport undermines urban livability and system efficiency.

Suggestions:

i. **Promote compact, transit-oriented development (TOD)** by embedding TOD principles in city master plans and revising land-use regulations to support high density, mixed-use development near transit hubs.

ii. **Expand and integrate mass transit systems** such as metro rail, Regional Rapid Transit System (RRTS), and formal bus networks, ensuring alignment with demand patterns and user preferences.

iii. **Ensure seamless last-mile connectivity** by linking major transit systems with electric feeder buses, mini-buses, and shared mobility services, while formalizing and regulating paratransit modes for safety and accessibility

iv. **Disincentivise excess usage of personal vehicles** by implementing congestion pricing, high parking fees, and ownership taxes in urban centres.

v. **Transition State Transport Undertakings (STUs)** from operators to regulators by adopting models such as gross contracting, where private operators run services under public oversight.

vi. **Establish Unified Metropolitan Transport Authorities (UMTAs)** in major cities to coordinate metro, buses, regional rapid transit (RRTS), and intermediate public transport (auto-rickshaws, e-rickshaws).

vii. **Strengthen investment in non-motorised transport** given its co-benefits for emissions, air quality, and public health.

viii. **Scale-up well-designed pedestrian pathways and cycling networks** across cities and towns to support a safe and inclusive infrastructure for everyday mobility.

2. Future-Ready Freight and Logistics

Challenge: Freight remains dominated by road (66.4% in 2025), with rail and waterways constrained by low speeds, capacity gaps, and poor multimodal integration[ii].

Suggestions:

i. **Promote freight modal shift to rail** by setting clear freight rail targets, supported by dedicated funding including exploring PPPs (double tracking, increased axle loads & train lengths, scaling DFCs), reform freight pricing system to make it more competitive, and provide assured and timely delivery of goods.

ii. **Scale up inland waterways and coastal shipping** by using public cargo (fertilizers, coal, etc.) to seed demand on priority routes, i.e., major rivers, the North-East, and coastal regions.

iii. **Maximize pipeline utilisation to decongest road and rail networks** through petroleum product pipeline grid by connecting all LPG and major petroleum distribution installations through pipelines. This strategic shift will free up critical capacity on rail and road networks, enabling them to better serve expanding passenger mobility and high-value freight segments

ii Rail carries ~22% of freight, with average freight speeds of ~19 km/h due to capacity constraints and mixed-traffic sections. Waterways carry ~7.6% of freight and remain underutilised because of shallow drafts, limited terminals, and weak multimodal integration.

iv. **Accelerate build-out of the national gas pipeline grid** by prioritising connectivity across industrial clusters, high-density freight corridors, urban transport zones, and hinterland regions to support wider adoption of CNG, LNG, and CBG.

v. **Future-proof all new pipeline infrastructure** by incorporating technical standards that can accommodate the eventual transport of green hydrogen, biofuels, and SAF.

vi. **Optimise locations for multimodal logistics infrastructure** including logistics parks, integrated freight corridors, and seamless trans-shipment facilities supported by an end-to-end digital logistics platform to enhance the competitiveness of rail and water-based freight systems.

vii. **Accelerate clean fuel infrastructure** by expanding the network of Battery Charging cum Swapping Stations (BCSS), and LNG fuelling stations along select high-density highways, logistics hubs, and industrial corridors, with mandated station density to ensure accessibility and commercial viability. To encourage setting up of a network of BCSS, Government may consider allotment of land on long term lease basis at concessional/promotional rates near the National Highways.

viii. **Strengthen domestic manufacturing for clean freight technologies** by supporting R&D and localisation of components, including advanced storage systems.

3. Enabling shift to clean fuels

Challenge: India's clean mobility transition faces multiple, interlinked challenges. Public charging infrastructure remains sparse and unevenly priced, driving range anxiety and slowing EV adoption, especially for high-utilisation fleets that need fast, reliable DC charging. Total Cost of Ownership (TCO) parity for EVs is largely limited to two-wheelers, as heavier vehicles remain costlier due to high battery costs. At the same time, challenges in domestic critical mineral extraction and refining make the EV supply chain highly import-dependent for critical minerals cells, chips, and power electronics, exposing India to price and geopolitical risks.

Complementary pathways are also underdeveloped. Flex-fuel[iii] and LNG vehicles[iv] could support hard-to-electrify segments. However, sparse retail fuelling infrastructure, pricing issues, OEM hesitation, low consumer awareness, and food–fuel concerns constrain scale. More broadly, the absence of clear, segment-wise Zero-Emission Vehicles (ZEVs) promotion and supporting incentives keeps overall penetration below its potential.

Suggestions:

i. **Raise regulatory ambition on efficiency and emissions** by strengthening CAFE III and IV norms progressively covering all vehicle categories and encouraging measures such as lightweighting and material efficiency.

ii. **Adopt a phased approach to Zero-Emission Vehicles (ZEVs)**: Begin with the phased elimination of the polluting vehicles and a shift to lower-emission options (CNG, hybrids, EVs). Subsequently, expand use of biofuels through FFVs, high CBG blends, and hybrid FFV models alongside continued EV growth. Finally, move to full deployment of ZEVs

iii Flex-fuel uptake remains limited due to sparse retail availability, OEM caution, and low consumer awareness.

iv LNG trucking faces high vehicle costs, limited OEM supply, and inadequate refuelling corridors

(EVs, Hydrogen based vehicles, FFV, and CBG based drivetrains), backed by segment-specific targets, timelines, and compliance mechanisms.

iii. **Build out supporting infrastructure at scale** by expanding EV, CBG, LNG, and flex-fuel refuelling/charging networks along highways, logistics hubs, industrial corridors, and priority freight routes, with minimum station density and focused deployment on the top 20 freight corridors.

iv. **Drive fleet transition to ZEVs through targeted incentives and aggregation** by using purchase subsidies, toll and tax exemptions, lower GST rates, and aggregated procurement of e-buses and e-taxis supported by risk-sharing guarantees and RESCO models to de-risk and lower upfront costs for public and commercial fleets.

v. **Embed EV readiness into urban and commercial infrastructure** by mandating EV-ready provisions in all new public buildings and a defined share of new private buildings, retrofitting existing public spaces, and providing time-bound capital and operational subsidies for charging infrastructure until it is commercially viable.

4. Strengthening Vehicle Retirement and Recycling

Challenge: End-of-life vehicle (ELV) recycling remains largely informal, with environmental risks and continued use of old, high-emission vehicles.

Suggestions:

i. **Build robust end-of-life vehicle (ELV) scrappage ecosystems** by mandating state-level scrappage policies aligned with the national framework, through PPPs and incentives from state governments.

ii. **Increase voluntary scrapping** using targeted financial incentives such as road tax waivers, reduced registration charges, combined with simplified registration and RTO fee structures and public awareness campaigns.

iii. **Strengthen battery end-of-life management** by ramping up collection of retired lithium-ion batteries, introducing deposit–refund or other recovery schemes, and adopting national guidelines for safe handling, transport, and storage.

iv. **Promote battery circularity and reuse** through standards for refurbished and second-life applications, circularity-friendly battery design, safety certifications, and dedicated R&D for sustainable recycling technologies, supported by a "Battery Aadhaar"[v] system for traceability, data management, and lifecycle monitoring.

v Digital battery traceability ("Battery Aadhaar") enables safer recycling, second-life use, and material recovery.

5.3 INDUSTRY

India's industrial sector has been modelled using a structured, bottom-up approach that links production activity with energy use and emissions outcomes. This study models nine major segments: cement, iron & steel, aluminium, textiles, paper & pulp, chemicals, chlor-alkali (soda ash and caustic soda), fertilisers, and aggregated other industry, covered under the Perform, Achieve, and Trade (PAT) scheme. The remaining industries are grouped under "other industries".

The modelling framework uses projected production output for each industry category as its core activity driver. Annual production forecasts are derived from macroeconomic indicators, sector-specific growth trajectories, and policy-linked targets, including those outlined under the Viksit Bharat vision.

For a complete methodology of production projection and detailed scenario assumptions related to the industrial sector energy transition, the Working Group Report on the Industry Sector (Volume 4) may be referred to. However, the broad results on total production, final energy consumption, and fuel mix are presented here.

5.3.1 Industrial Production and Energy Demand

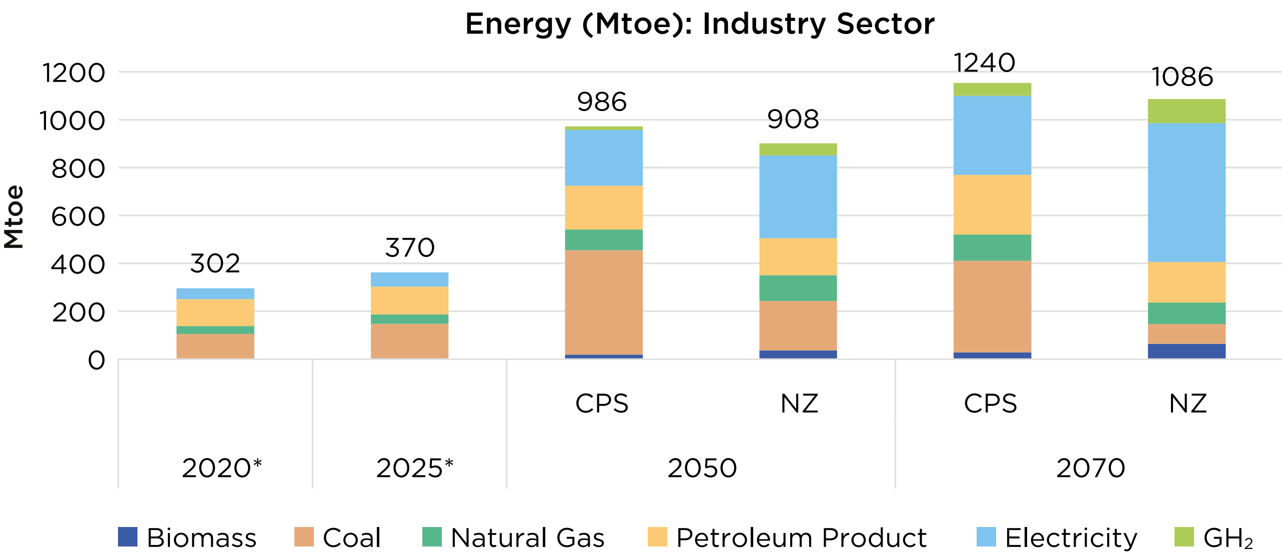
In 2023, the production in various industrial segments was: Steel–120 MT, Cement–360 MT, Aluminium–5.4 MT, Textiles–7.46 MT, Fertilisers–38 MT, Chlor-alkali–6.54 MT, Ethylene–6.41 MT, and Paper & Pulp–22.43 MT. Using the methodologies outlined in the Working Group report on the Industry sector, the projected production for each segment is presented in Figure 5.9.

Figure 5.9: Projected growth in industrial production for 2050 and 2070, in multiple of 2020 values

In addition to activity levels, the model incorporates specific energy consumption (SEC) and fuel mix as inputs, with values differentiated by technology. Based on scenario definitions, each sub-sector is mapped to its prevailing technology pathways and the corresponding SEC and fuel consumption patterns. This includes distinguishing between thermal and electrical energy (grid and captive) and identifying the fuel mix, such as coal, petroleum products, natural gas, electricity, and renewable sources. Energy demand is then calculated by multiplying estimated production volumes with sub-sector- and technology-specific energy intensity values (in Giga Joules or Tonnes of Oil Equivalent per tonne).

India's industry sector consumed about 302 Mtoe of energy in 2020 and 369 Mtoe in 2025[vi], dominated by coal and fossil fuels. In the fuel mix for 2020, coal supplied roughly 34% of energy demand, followed by petroleum products (37%), natural gas (12%), electricity (15%), and 1% biomass (see Figure 5.10). Within this, a sizeable fraction of fuels is used as feedstock rather than for combustion, e.g. naphtha/natural gas in chemicals and petrochemicals and natural gas in ammonia/urea, creating process-related emission profiles distinct from those of fuel use.

The Current Policy Scenario (CPS) reflects continuation of current policies, with gradual improvements in energy efficiency, moderate fuel diversification, and incremental adoption of cleaner technologies, leading to modest carbon reductions per unit of output. In contrast, the Net Zero Scenario (NZS) represents a transformative pathway toward India's Net Zero target by 2070, assuming proactive policies, accelerated innovation, and a system-wide shift to electrification, low-carbon fuels, circular economy practices, and carbon capture, guided by global best practices. However, both the scenarios use the same production projections.



* *This includes fuels for non-energy uses, as well as consumption categorised under the "non-specified" category and statistical differences in the MoSPI energy balance, which are assumed to be captured within the "Other Industries" category, after accounting for transport sector allocations.*

Figure 5.10: Projected energy consumption in industry sector for 2050 and 2070 under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Under Current Policy Scenario (CPS), industrial energy consumption is projected to rise from 369 Mtoe in 2025 to 1,147 Mtoe by 2070, a three-fold increase in industrial commodity demand. Although the share of fossil fuels declines modestly from 83% to 72%, the sector remains heavily dependent on them. Electrification is projected to grow gradually, from 16% to 29% by 2070,

vi This includes fuels for non-energy uses, as well as consumption categorised under the "non-specified" category and statistical differences in the MoSPI energy balance, which are assumed to be captured within the "Other Industries" category, after accounting for transport sector allocations.

but the sheer scale of industrial expansion leads to a 2.7-fold increase in absolute coal and natural gas demand, reinforcing the dominance of fossil energy.

In contrast, Net Zero Scenario's (NZS) energy demand is lower by 15% as compared to CPS by 2070 through enhanced efficiency, electrification, waste heat recovery, and circularity. Clean energy carriers, electricity and green hydrogen, emerge as the backbone of industrial energy, reducing coal's projected share to 7.6% (from 35% under CPS) and petroleum to 11% (from 17% under CPS). This transition requires electrification, hydrogen deployment for high-temperature processes, and a shift to renewables, significantly cutting emissions and import reliance.

By 2070, electricity, green hydrogen, and biomass are collectively projected to meet 74% of industrial energy demand in Net Zero Scenario (NZS), almost double the 39% projected share under Current Policy Scenario (CPS), but demand large-scale infrastructure investments to realise. Electrification is projected to rise from 16% to 55% in NZS by 2070. Further, with expected improvements in the reliability of grid, in both scenarios, the captive share of electricity is expected to decline from 30% in 2024 to 23% under NZS by 2070.

Current policies lock India's industry into fossil energy; Net Zero path cuts demand and transforms the fuel mix.

Role of Green Hydrogen (GH_2)

In industry, hydrogen is a critical decarbonisation vector for many high-emission processes—serving as a clean reducing agent in ironmaking, a zero-carbon feedstock for ammonia and fertiliser production, and a desulfurisation agent in refineries. From a near-zero green baseline in 2020 (when hydrogen use was mostly grey and concentrated in refineries and fertiliser plants), the two scenarios (CPS and NZS) diverge sharply.

i. In the CPS, GH_2 grows as a supplement to fossil-fuel based production routes. Total demand is projected to reach about 5 Million Tonne (M)t in 2050 and 19 Mt in 2070. Sectoral demand shifts progressively toward steel, with consumption of about 13 Mt in 2070, while fertilisers account for roughly 3.5 Mt, and refineries for around 2 Mt.

ii. In the NZS, GH_2 becomes a core decarbonisation fuel. Industrial hydrogen demand rises to 17.4 Mt in 2050 and 35 Mt in 2070, almost double that under CPS. Steelmaking is the anchor load (28 Mt in 2070) as hydrogen-based DRI/EAF replaces coal. Fertilisers transition to green ammonia (4.5 Mt), and refineries shift to green hydrogen (2.3 Mt) for hydrotreating processes (desulfurisation, denitrogenating, and deoxygenation).

Circular Economy

India's industrial base remains heavily dependent on primary materials; cement production is clinker-intensive, and steel manufacturing primarily relies on iron ore-based routes. To address the domestic shortage of scrap, India supplements its supply through imports. In 2023, the country was the world's second-largest importer of ferrous scrap, at almost 11.5 million tonnes. Circular economy can bend these trajectories by 2070.

i. Cement: The clinker ratio is projected to fall from 0.67 in 2024 to 0.60 in Current Policy Scenario (CPS) and 0.55 in Net Zero Scenario (NZS) by 2070. Cement production is projected to reach 1,985 Mt in same duration. This implies ~100 Mt clinker is avoided annually through use of higher supplementary cementitious materials (SCMs) such as slag, calcined clay, limestone, fly ash or natural pozzolans.

ii. **Steel's scrap**/Electric Arc Furnace (EAF) share increases from 18% in 2025 to 40% by 2070, and aluminium's secondary share rises from 31% in 2025 to 40%.

The proposed production pathways could avoid tens of millions of tonnes of primary demand and provide scale for secondary commodities, reducing energy use and process CO_2 emissions. This would also lower reliance on imported coking coal while strengthening domestic scrap collection and processing to meet future demand locally.

India's industry shifts from primary dependence to a circular materials in future; circularity begins to reshape India's cement and steel trajectories; scrap becomes the new backbone of India's steel growth

Carbon Capture

Even after higher efficiency in energy use, electrification, circularity, and using green hydrogen, India's industry retains a large "hard" core of process CO_2 (cement calcination, steel off-gases, aluminium anode) and residual fuel/feedstock emissions such as in petrochemicals production.

i. Under CPS, no CCUS is assumed to be installed, so these emissions remain unabated.

ii. In the NZS, carbon capture scales as the last-mile lever: rising from pilot volumes in 2035 to around ~35 $MtCO_2$/yr by 2050, then expanding with CO_2 hubs, pipelines, and saline storage to roughly ~1,000 $MtCO_2$/yr by 2070 covering essentially all point-source-amenable residuals.

5.3.2 Challenges and Suggestions

Industrial decarbonisation requires a mix of efficiency, electrification, new technologies, recycling, finance, and skilling.

1. Improving Energy Efficiency

Challenge: India has demonstrated significant progress on energy efficiency. Programmes like Perfom, Achieve and Trade (PAT) have shown that market mechanisms work (~8% annual savings across designated entities by 2022-23). A key gap lies in improving efficiency of MSMEs owing to lack of real-time monitoring, lack of capital for upgrades, higher credit costs due to weak balance sheets and lack of awareness.

Suggestions:

i. **Increase audit frequency for high-intensity processes** and deploy ISO 50001-aligned digital monitoring leveraging IoT and AI tools.

ii. **Scale up the Assistance in Deploying Energy Efficient Technologies in Industries and Establishments (ADEETIE) scheme** by rapidly operationalizing it in key industrial clusters. Using ESCO/RESCO models, ADEETIE can bundle interest subvention, energy audits, Detailed Project Reports (DPRs), and Monitoring and Verification (M&V) to deliver priority retrofits (e.g., heat pumps, variable-speed drives, waste-heat recovery) and on-site clean power with low upfront costs.

iii. **Considering Waste Heat Recovery** as RE for the purpose of Renewable Consumption Obligations (RCOs)

iv. **Publish simple, sector-wise benchmarks and retrofit menus** (textiles, foundries, etc.) to cut search and transaction costs.

2. Circularity in Manufacturing

Challenge: Industrial decarbonisation is slowed by heavy reliance on virgin materials, low recycling and reuse rates, especially in industrial sectors such as textiles, pulp and paper, and construction and demolition waste. Circularity is further constrained by the dominance of informal scrap collection and processing, low-quality and contaminated scrap, and limited deployment of advanced sorting and recycling technologies. India's growing dependence on imported scrap exposes industry to global policy shifts, export restrictions, and price volatility.

Suggestions:

i. **Extended Producer Responsibilty (EPR) backed circularity and compliance:** Strengthen EPR frameworks in plastics, e-waste, and autos by tightening recovery and recycling obligations, supporting audits, certification, and traceability. Expand EPR to additional areas such as textiles, footwear, batteries, etc. Further, implement minimum recycled content mandates where feasible.

ii. **Notify Green Public Procurement (GPP) norms**, which will incentivise use of BIS-labelled recycled material. BIS norms will ensure quality standards for secondary materials.

iii. **Industrial symbiosis with clear standards:** Promote "waste exchange" clusters, whereby by-products of one industry (e.g., slag, sludge, heat) become inputs for another under robust technical standards(e.g. steel slag to cement, fly ash to concrete, textile waste to insulation).

iv. **Promote Unified waste management license** enabled through a digital single-window system with time-bound approvals.

v. **Establish decentralised and common pre-processing infrastructure in MSME clusters** (drying/shredding/baling) near waste sources to densify materials, reduce transport costs, and ensure consistent quality for industrial users.

vi. **Integrate informal workers** into EPR supply chains via verified IDs, training and Personal Protective Equipment (PPE).

vii. **Promote Transparent, investable circular markets:** Organise scrap auctions, adopt index-linked pricing, enable digital material-flow tracking, and use fiscal levers such as tipping fees for waste use, rationalise GST and import duties to favour recycling.

3. Electrification of Industrial Energy Demand

Challenge: Only 16% of industrial energy demand is electrified. Barriers include high industrial tariffs (cross-subsidised in favour of households), unreliable 24×7 green power, regulatory hurdles for green open access, and high capex for electric boilers, furnaces, and heat pumps. MSMEs face the steepest hurdles.

Suggestions:

i. **Reform power pricing** so that industrial tariffs reflect the true cost of electricity, improving the business case for electrification and flexible, demand-aligned consumption. Facilitating timely approvals for industry seeking Green Energy Open access.

ii. **Develop dedicated power feeders for industrial zones** which can provide assured 24×7 grid power, reducing dependence on self-generation and encouraging industries to shift to cleaner electricity sources.

iii. **Promote and scale RESCO models** that aggregate demand, achieve economies of scale, and offer professional energy management services, reducing the operational burden on individual industries. Scale implementation of Firm Dispatchable Renewable Energy (FDRE) contracts through deployment of Hybrid plants matching industrial load profiles.

iv. **Develop a sector-wide electrification map** linking temperature ranges, processes, and available electrification technologies to guide industries in sequencing their transition.

v. **Promote blended finance instruments** with assured green premiums for mature electric technologies such as electric boilers, where high operating costs limit adoption despite technical and cost competitiveness.

4. Deployment of New Technologies & Fuels

Challenge: Deployment of frontier low-carbon technologies such as H_2-DRI steel, CCUS for cement, inert anodes in aluminium, and Limestone Calcinated Clay Cement (LC3) remain early-stage and expensive. Private sector hesitates to invest in "First-of-a-Kind" (FOAK) commercial-scale projects due to technical risks and uncertain returns. Green alternatives have high upfront costs with uncertain returns

Suggestions:

i. **Scale up pilot and demonstration projects** in H_2-DRI, inert anodes in aluminium, LC3 cement, blue ammonia plants, and CCUS-equipped cement plants to prove technical feasibility, build investor confidence, and reduce perceived risk.

ii. **Ensure assured offtake** through creation of buyer's platform for low-carbon products such as Sustainable Aviation Buyers Alliance, the Zero Emissions Maritime Buyers Alliance and the Sustainable Steel Buyers Platform. These platforms can also leverage Article 6.2/Article 6.4 for enabling trade in low-carbon products.

iii. **Strengthen climate taxonomies** to explicitly include all low-carbon process routes/ technologies, with clear benchmarks, and thresholds. Harmonise definitions and reporting boundaries with major international frameworks to reduce transaction costs and uncertainty for investors. Government and industry bodies to roll out Type III eco-labels and rating systems for key materials.

5. Employment Risks and Opportunities

Challenge: Rapid adoption of low-carbon and digital technologies is already outpacing workforce readiness. Low technical and digital skills are creating a transition gap that needs to be addressed on priority.

Suggestions:

vi. **Sector Skill Councils (SSCs) should institutionalise continuous collaboration with industry partners and ITIs** to ensure that training curricula and occupational standards are regularly updated in line with evolving skill requirements. Certification systems must be strengthened through employer-led assessments and periodic third-party audits so that SSC credentials gain stronger labour market credibility and wage signalling value.

vii. **Emphasise on-the-job training and practice-oriented courses** to upskill the existing workforce, particularly in emerging technologies and new production processes.

viii. **Develop sector-specific transition skill roadmaps** to identify at-risk occupations and facilitate reskilling into low-carbon roles, enabling firms and workers to adapt smoothly to decarbonisation pressures.

ix. **A national skills intelligence system** should be developed to generate forward-looking labour market information and forecast future skill demand at sectoral and regional levels.

6. International Competitiveness and Trade

Challenge: Indian industry faces rising exposure to global climate-related trade measures, including the European Union's Carbon Border Adjustment Mechanism (CBAM) beginning 2026, and growing resource nationalism (scrap export bans and taxes from the EU, China etc). Domestically, high import tariffs on intermediate goods can raise input costs, while strong competition from China, Vietnam, and Bangladesh pressures export competitiveness.

Suggestions:

i. **Accelerate low-carbon transition in export-oriented sectors** to upgrade competitiveness. Leverage domestic carbon pricing i.e. Carbon Credit Trading Scheme (CCTS) and Article 6.2/6.4 of Paris Agreement to enable the use of low-carbon technologies/fuels.

ii. **Institutionalise a periodic "tariff stocktake"** to assess impact on domestic manufacturing.

iii. **Launch a "Green Stamp" initiative for exports** to certify and showcase the environmental footprint of Indian products. Develop standardised assessment frameworks (analogous to the EU's Product Environment Footprint Category Rules (PEFCR) guidelines) for priority export sectors, create credible lifecycle assessment (LCA) data repositories, and implement digital product passports that track product sustainability attributes.

5.4 BUILDINGS

The building sector covers residential, commercial, and cooking segments. This chapter estimates the operational energy use for services such as lighting, cooling, appliances, and cooking. It has excluded embodied and end-of-life emissions. These embodied emissions are indirectly accounted for in the industry section, while estimating demand of construction materials such as steel, cement, aluminium etc.

Energy demand is estimated using sector-specific methodologies that account for economic growth, urbanisation, climate, technology transitions, and household behaviour. This is aligned with approaches adopted by leading national and expert institutions to ensure robustness and consistency with broader macroeconomic trends.

For a complete methodology and detailed scenario assumptions related to the building sector energy transition, the Working Group Report on the Building Sector (Volume 5) may be referred to. However, the broad results on total electricity consumption in commercial, residential and fuel mix in cooking sector are presented here.

5.4.1 Commercial Buildings

Commercial sector energy demand is estimated using a bottom-up model that considers projected floor space (linked to service sector employment), building typologies, and Energy Performance Index (EPI) values for air-conditioned (AC) and non-air-conditioned (Non-AC) areas. As the service sector expands and urban centres modernise, commercial floor space is expected to increase leading to significant increase in energy use. The model factors in energy savings from Energy Conservation and Sustainable Building Codes (ECSBC), ECSBC+ and Super ECSBC compliant buildings. In 2025, electricity demand of the commercial building sector was about 137 TWh.

In this sector, differences across scenarios are driven by the changes in the Energy Performance Index (EPI) and adoption of low-carbon building standards. Efficient appliances reduce EPI by ~10% in Current Policy Scenario (CPS), limited by older stock and retrofit scope, and by ~15% in Net Zero Scenario (NZS). This is through higher deployment of Building Energy Management Systems (BEMS), occupancy-based controls, and improved Heating Ventilation and Air Conditioning (HVAC) zoning. Floor area assumptions remain same in both scenarios.

Average EPI (AC+non-AC) for a particular building category is expected to rise slightly due to the growing share of AC floor space under both scenarios, which is inherently moderated through adoption of efficient building codes. By 2070, efficient building penetration is assumed to reach 35% (20% ECBC, 10% ECBC+, and 5% Super ECBC) in CPS. In NZS, it reaches 60% (30% ECBC, 20% ECBC+, and 10% Super ECBC). With the combined effect of reduction in EPI, increase in AC floor space and penetration of efficient buildings, the reduction of effective EPI is 11% in CPS and 20% in NZS by 2070.

Accounting for projected floor space and AC share along with effective EPI values, the total commercial electricity demand (excluding data centres) is projected to rise to 504 TWh under CPS and 428 TWh under NZS by 2070 (Figure 5.11). This is because of stronger building codes, enhanced energy management, and widespread efficient HVAC and lighting deployment.

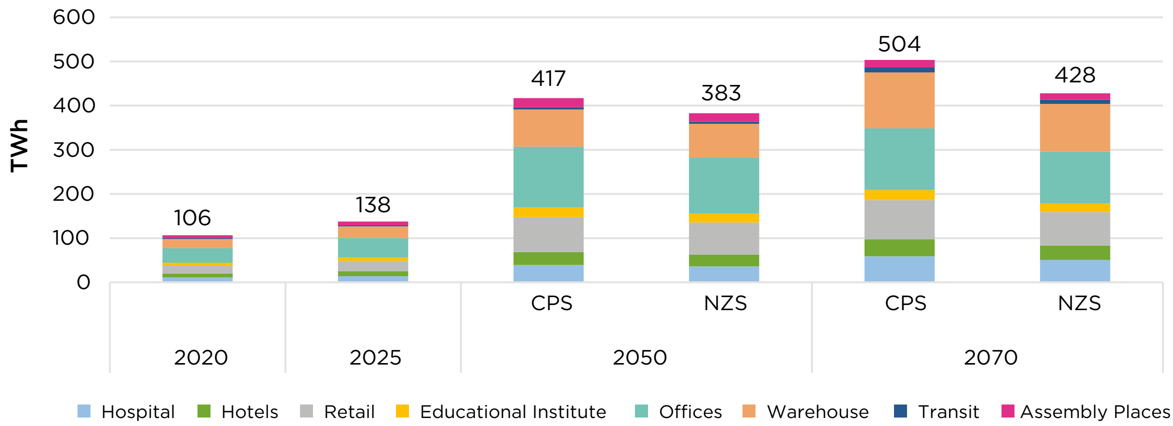


Figure 5.11: Projected electricity consumption in commercial building sector by 2050 and 2070 under Current Policy Scenario (CPS) and Net Zero Scenario (NZS), Terawatt-hour (TWh)

5.4.2 Residential Buildings

Residential energy demand is modelled using a bottom-up, appliance-based approach that reflects India's consumption patterns, where energy use is driven by appliance ownership and usage. Demand is projected by estimating appliance stock, based on the number of households, appliance penetration rate, and average units per household, and appliance-specific power ratings and usage hours. These include services like lighting, cooling, refrigeration, water heating, pumping, and washing. Electric Vehicles (EVs) charging is excluded and covered under the transport sector. The model incorporates expected improvements in appliance efficiency and behavioural changes over time for usage pattern and hours, with separate assumptions for urban and rural segments.

Electricity consumption in the Residential Sector evolves from a profile dominated by lighting and other appliances towards one shaped by cooling requirements (see Fig 5.12). Rising incomes, urbanisation, and improved access to electricity are the main drivers, coupled with higher expectations for thermal comfort. Residential electricity demand is projected to increase from 385 TWh in 2025 to 1,290 TWh in Current Policy Scenario and 925 TWh in Net Zero Scenario by 2070.

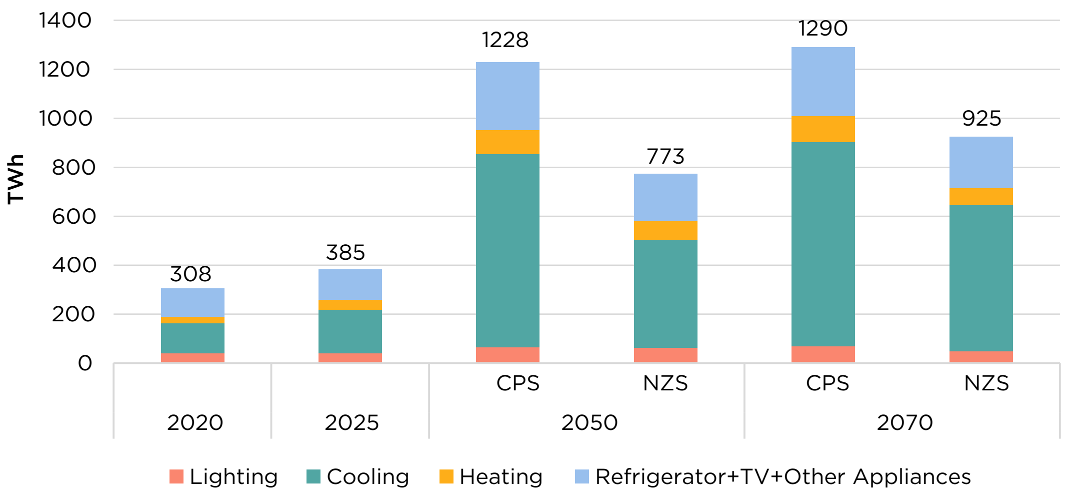


Figure 5.12: Projected electricity consumption in residential building sector by 2050 and 2070 under Current Policy Scenario (CPS) and Net Zero Scenario (NZS), Terawatt-hour (TWh)

Cooling demand is the standout: Under Current Policy Scenario (CPS), cooling demand is projected to reach 834 TWh in 2070. Under Net Zero Scenario (NZS), higher use of efficient ACs, adoption of Eco-Niwas Samhita standards in new homes, and Mission LiFE behaviour shifts lead to a lower cooling demand at around 596 TWh by 2070. Other appliances such as refrigerators, washing machines, televisions also expand rapidly, with total residential electricity demand expected to more than triple by 2070 under the CPS, but slightly lower under NZS through technology and efficiency gains.

Heating, which includes both space and water heating, is gaining significance with the affordability of electric and solar geysers and space heating needs in colder regions. Under the CPS, electricity demand from this segment is expected to grow from 43 TWh in 2025 to 96 TWh by 2050 and 106 TWh in 2070. Under NZS, with more efficient technologies, demand is projected to reach 76 TWh in 2050 and thereafter reduce to 70 TWh by 2070.

Other appliances, covering refrigerators, televisions, washing machines, and other household devices reflect India's improving living standards. Under the CPS, electricity use for other appliances is expected to grow from 123 TWh in 2025 to 277 TWh by 2050 and 281 TWh by 2070. Under NZS demand is projected to reach 192 TWh by 2050 and to 210 TWh by 2070 (See Figure 5.12).

5.4.3 Cooking Sector

Cooking, a daily necessity in every household, is also at the heart the country's energy transition. To understand this shift, the analysis begins with a simple premise: the energy required to cook a meal. Using average per capita daily useful energy needs, benchmarked against national and international studies, the study estimates total demand based on population and household size, accounting for differences in urban and rural fuel access. The model does not separate residential from commercial cooking, reflecting the blurred lines in real-world usage. Total demand is derived from population and household size, differentiated by urban–rural fuel access. Final energy use is calculated by applying fuel-specific efficiencies across LPG, PNG, electricity, biomass, and biogas, with fuel shares projected based on adoption trends, urbanisation, policies, and technology progress.

Even as cleaner fuels like LPG became more widely available, many rural families continue to "fuel-stack," blending LPG with biomass to balance affordability and availability. This practice, while pragmatic, slows the transition to cleaner cooking.

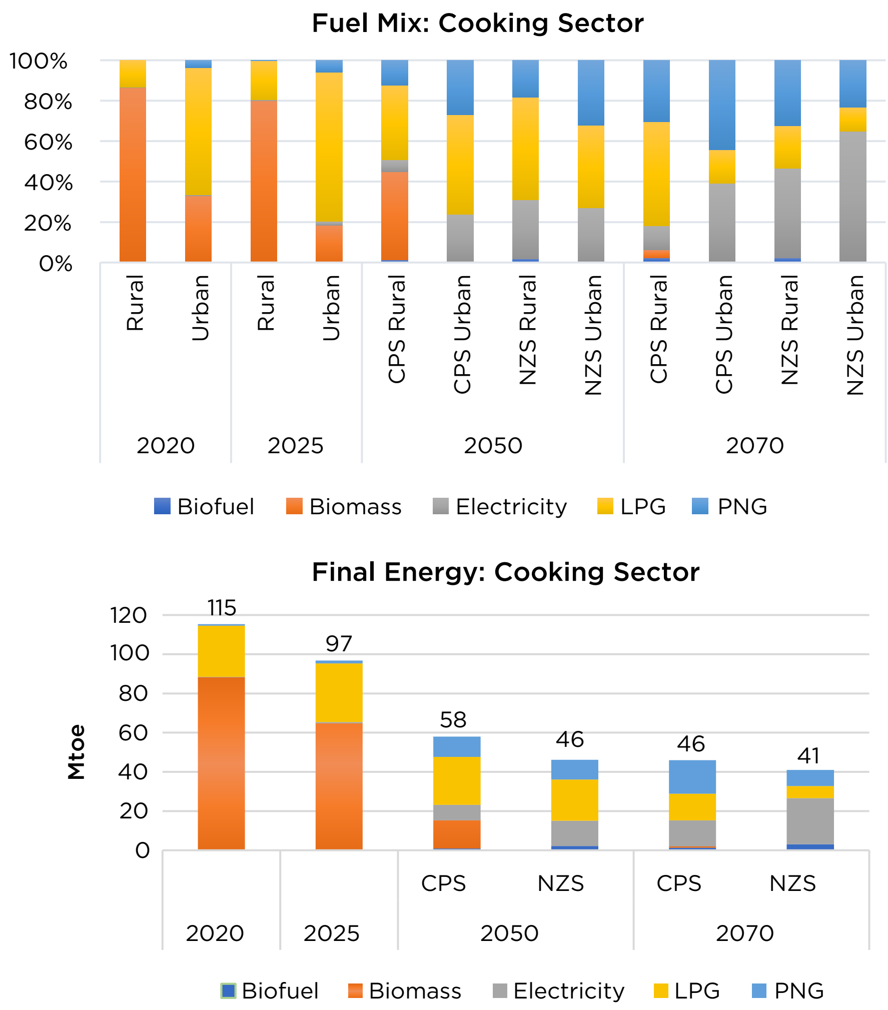
The inefficiency of traditional fuels for cooking is apparent. Biomass supplied over 75% of India's cooking energy in 2020, but delivered only about 40% of the actual cooking service. In contrast, LPG, used more efficiently, accounted for just 22% of energy input but met nearly 57% of cooking needs. Piped natural gas (PNG) and electricity were emerging options, mostly in urban areas, while biogas remained marginal.

This snapshot of 2020 reveals both the challenges and the opportunities in India's cooking energy landscape. As shown in Figure 5.13, scenario results reveal that:

i. Under Current Policy Scenario (CPS), urban households largely stop using biomass after 2045; rural use reduces sharply and becomes negligible by 2070. LPG remains a significant source through mid-century but gradually reduces as pipeline network expands. By 2070, PNG is the leading carrier in this sector, electricity gains a meaningful share, LPG remains significant, and bio-CNG also is in use at a low share.

ii. Under Net Zero Scenario (NZS), the fuel mix evolves more rapidly. Traditional biomass use stops by 2040s; PNG rises to 20%, electricity share more than 50%, LPG reduces to 15%, and Bio-CNG reaches approximately 7% by 2070.

Across both pathways, total cooking energy consumption declines substantially, from about 97 Mtoe in 2025 to 46 Mtoe (in CPS) vs 41 Mtoe (in NZS) by 2070. The reduction is driven by end-use efficiency gains associated with the shift from traditional biomass to LPG/PNG and electric options. The transition delivers significant health benefits and time savings especially for rural households alongside emissions reductions.



Note: CPS - Current Policy Scenario; NZS - Net Zero Scenario

Figure 5.13: Projected fuel consumption in cooking sector by 2050 and 2070 under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Across both Current Policy Scenario (CPS) and Net Zero Scenario (NZS), India's transition from biomass to LPG, PNG, electricity, and bio-CNG cuts total cooking energy use by over half by 2070, delivering significant health and emissions benefits, especially for rural households.

5.4.4 Emerging Load: Data Centre Facilities

Data centre demand is projected using IT load[vii] growth and power usage effectiveness (PUE) over time. High energy intensity and continuous operation mean that data centres are a distinct and increasingly relevant end-use category within the commercial sector. Their energy demand is estimated using:

Electricity Demand = IT Load Capacity   Utilisation Factor   Power Usage Effectiveness (PUE)

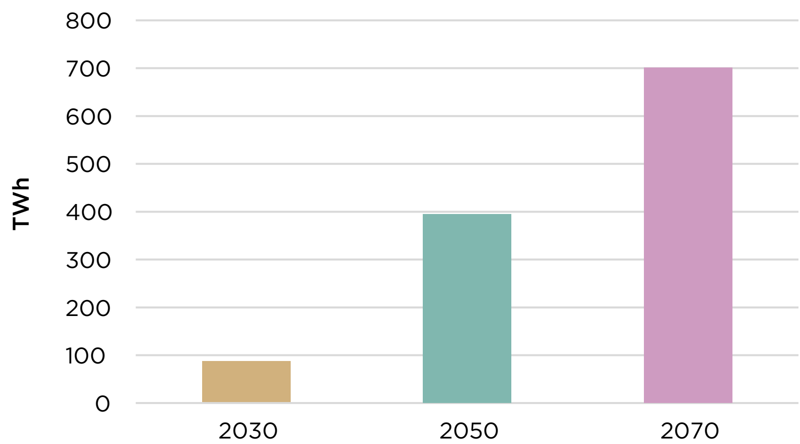


Figure 5.14: Projected electricity consumption in data centres, Terawatt-hour (TWh)

India's IT load capacity is projected to reach 4 GW by 2030, largely driven by data localisation policies and digital service expansion. At a typical utilisation rate of 40% and a PUE of 1.6, this translates to an estimated electricity demand of around 2.6 GW in 2030.

In the medium-term (2030–2047), IT load is expected to grow at 12% per annum due to AI integration. By 2047, IT load is projected to reach 65 GW, UF to 50% and PUE dropping to 1.4, resulting in a total electricity demand of approximately 45 GW (394 TWh).

In the long-term (2047–2070), the integration of quantum computing and further digitalisation is expected to sustain growth at 6% per annum. By 2070, IT demand could reach 105 GW, with further operational improvements (UF at 60% and PUE at 1.3), resulting in an estimated energy demand of about 80 GW (700 TWh).

These projections underscore the increasing importance of data centres in national energy planning. While their energy footprint expands, efficiency improvements through optimised cooling systems, renewable energy integration, and advanced power management can help moderate their energy demand.

5.4.5 Challenges and Suggestions

More than 80% of the floor space that will exist in 2050 is yet to be built, making it both an opportunity and a risk. If construction follows business-as-usual practices, India will lock in high energy demand and emissions for decades. While appliance efficiency schemes (like UJALA and the Bureau of Energy Efficiency's Standards & Labelling scheme) have delivered gains,

vii Projections of IT load for data centres are undertaken via extensive stakeholder consultation building codes remain narrow in scope and weakly enforced. Embodied carbon, passive design, and retrofit measures receive limited attention.

1. Building Codes coverage and performance

Challenge: India's building codes remain narrow in scope and weakly adopted, with several states and Union Territories yet to notify them[viii]. Residential codes are largely voluntary and have seen minimal uptake[ix]. No code applies to the vast stock of existing buildings.

Even where codes are in force, they focus mainly on design-stage operational energy and exclude whole-life and embodied carbon, passive design, thermal-envelope performance, heat-resilience standards, and commissioning protocols. These gaps risk locking in buildings with high cooling loads, costly retrofits, and poor resilience.

Suggestions:

1. **Upgrade existing codes** by adding mandatory thermal-envelope performance thresholds**,** whole-life and embodied-carbon metrics**,** heat-resilience standards**,** and commissioning protocols to ensure long-term efficiency at minimal additional cost.
2. **Expand coverage via tiered framework for commercial buildings**: Full Energy Conservation and Sustainable Building Code (ECSBC) for large commercial and simplified codes for small commercial reflecting proportionality of regulatory burden.
3. **Promote Eco-Niwas Samhita (ENS) for new large residential buildings (>500 metre2)** with Residential Envelope Transmittance Value (RETV) threshold set according to Climate zones.
4. **Develop a retrofit code for existing stock,** triggered at major renovation or change-of-use, requiring measured Energy Performance Index (EPI) disclosure.
5. **Set a phased, time-bound pathway** that progressively aligns all codes with India's Net Zero objectives while giving industry clear visibility on future tightening.

2. Building Code Implementation and enforcement

Challenge: Adoption and compliance vary widely across states and Union Territories. Many Urban Local Bodies (ULBs) depend on manual and self-declared processes, lack skilled staff, and have too few qualified assessors. Clear, enforceable penalties are missing, and fragmented systems prevent the creation of reliable national datasets.

Suggestions:

i. **Standardize & professionalize Third Party Assessors (TPAs)** through a national registry with uniform eligibility, training, and protocols, recognised across all states/UTs; mandate TPA reviews at design-stage and during the site inspections.

viii The Energy Conservation Building Code (ECBC) and the Energy Conservation and Sustainable Building Code (ECSBC) apply only to new commercial buildings above 100 kW (or 120 kVA in some states) and remain unadopted in 10 states and 3 Union Territories.

ix The Energy Conservation Building Code for Residential (ENS) is voluntary for plots above 500 m^2, and the new ECSBC-R (2024) is yet to be adopted by states and UTs.

ii. **Promote digital-by-default compliance** by ensuring every state/UT operates a common ECBC/ECSBC/ECSBC-R portal for submissions, reviews, approvals, audits, and updates built on shared data schemas and APIs that feed into a national dashboard.

iii. **Define clear, enforceable penalties for non-compliance,** including withholding occupancy certificates and essential service connections (electricity, water, telecom) until issues are rectified and publish non-compliance and remediation status on the portal for transparency.

3. Market Development and Innovation

Challenge: There is a need for a mature ecosystem for low-carbon, efficient, and resilient buildings. Consumers have little information on building performance, benchmarking frameworks are weak, and incentives are inconsistent. Appliance demand is booming, but the Standards & Labelling (S&L) programme and Minimum Energy Performance Standards (MEPS) lag global best practice.

On the supply side, domestic manufacturing remains import-dependent for key appliance components, embodied-carbon benchmarks are absent, public procurement ignores lifecycle emissions, and greenwashing risks persist. Data gaps such as no embodied carbon database, scarce measured building-performance data, and little feedback from demonstration projects limit market confidence.

Suggestions:

i. **Demand-side**:

- **Phased introduction of Environmental Product Declarations (EPDs)** for building materials & products. Develop Product category rules (PCRs) for materials used in construction such as steel, brick, admixtures, etc. to enable EPD measurement. Further, create an inventory of accredited EPDs.
- **Adopt green public procurement** by updating schedules of rates to include low-carbon, EPD-certified products, creating large-scale demand and economies of scale.
- **Design and implement financial incentives for green buildings** linked to % improvement over ECSBC and ENS. Incentives may be provided both for developer and end customer (e.g., stepped increase in FAR depending on modelled EPI for developer and rebate on property taxes for buyer).
- **Strengthen appliance efficiency** by expanding BEE's Standards & Labelling (S&L) programme to cover heat pumps, evaporative coolers, fans, pumps, and TVs, including refrigerant emissions; strengthening third-party testing and enforcement to include green labelling of products and appliances.

ii. **Supply-side**

- **Upgrade Minimum Energy Performance Standards (MEPS)** to align thresholds with international best practice and tighten regularly.
- Implement a **super-efficient appliances programme** targeting Brushless Direct Current (BLDC) fans, air conditioners, and refrigerators.

- **Boost domestic manufacturing** by strengthening Production-Linked Incentive-White Goods (PLI-WG) scheme, simplifying access, broadening technology coverage (e.g., heat pumps, electronics), and enabling MSME participation.
- **Accelerate secondary material use** through incentives for Construction & Demolition (C&D) waste and industrial/agri by-products, use mechanisms such as landfill taxes to redirect waste streams.

iii. **Cross-cutting**

- **Establish a national building-data public platform** integrating real-world performance, appliance test data, India-specific EPD database for embodied carbon disclosure and retrofit outcomes. Use insights to refine codes, standards, and incentives.
- **Create a dedicated program** to encourage R&D for green/ low-carbon materials and products, along with commercialisation support to bring the products from lab to demonstration projects.
- **Provide support for commercialisation through RESCO/ESCO models** targeting low energy and low-cost cooling, low-carbon masonry, prefabricated systems, high-performance envelopes.

4. Workforce Capacity and Skills

Challenge: The building workforce, including architects, engineers, masons, HVAC installers, and facilities managers, lacks targeted training for low-carbon construction. Most existing programs do not focus on low-carbon materials, energy management, or new technologies. The informal sector, which dominates construction, is largely excluded from training initiatives. Training efforts are spread across institutions with weak coordination and monitoring, and no central feedback mechanism. As a result, the sector is not well prepared to deliver the next generation of energy-efficient and climate-resilient buildings.

Suggestions:

i. **Design dedicated curricula** for architects, engineers, trades, and facility managers, covering low-carbon materials (e.g., alternative cements, agrocrete blocks), building energy management, and installation of solar PV, HVAC, and insulation systems.

ii. **Integrate sustainability modules** into national skilling schemes, including the Pradhan Mantri Kaushal Vikas Yojana (PMKVY), Accelerated Mission for Better Employment and Retention (AMBER), and PM Vishwakarma.

iii. **Include the informal workforce** by delivering outreach and training through local building centres, SHGs, and cooperatives, ensuring last-mile capacity building.

iv. **Encourage developers and real estate companies** to invest CSR funds in workforce skilling for green construction practices.

v. **Strengthen certification and monitoring** via accredited courses on sustainability and operational-energy management, along with a central mechanism to assess, track, and update skills programs.

vi. **Build regulatory and enforcement capacity** by training ULB officials and code assessors in ECSBC/ENS compliance, modern technologies, and best practices, and significantly scale up the pool of State Designated Entities.

5.5 AGRICULTURE

Agriculture modelling is examined for: (i) Agricultural services that generate non-energy emissions, such as rice cultivation, soil management, agricultural residue burning, enteric fermentation, and manure management), and (ii) Energy consumption services, such as irrigation pumping and land preparation, which drive energy-related emissions.

For a complete methodology and detailed scenario assumptions related to the agriculture sector energy transition, the Working Group Report on the Agriculture Sector (Volume 6) may be referred to. However, the broad results on non-energy emissions, final energy consumption, and fuel mix are presented here.

5.5.1 Agriculture Non-Energy Services

Livestock enteric fermentation, rice cultivation, and fertiliser application are major agriculture sources of non-CO_2 GHGs. This is primarily from methane (CH_4) and nitrous oxide (N_2O), whose global warming potentials (GWP) are 28 and 265 times that of CO_2 respectively over 100 years (IPCC 2014). In 2020, agriculture contributed 76% of India's CH_4 and 70% of its N_2O emissions, driven by enteric fermentation from livestock, rice cultivation, and synthetic fertiliser use.

The emissions projections methodology follows a two-step process:

1. **Projecting production**: Baseline data (2019 and earlier) for key crops and livestock are used to project future production for eight key crops and milk, based on farming practices, input use, and supply-demand trends. Production trajectories are common to both scenarios.
2. **Estimating emissions:** Projected production is combined with India-specific emission factors aligned with international standards. The main assumptions and interventions used for projecting agricultural emissions are detailed in the working group report on agriculture Sector (Vol. 6).

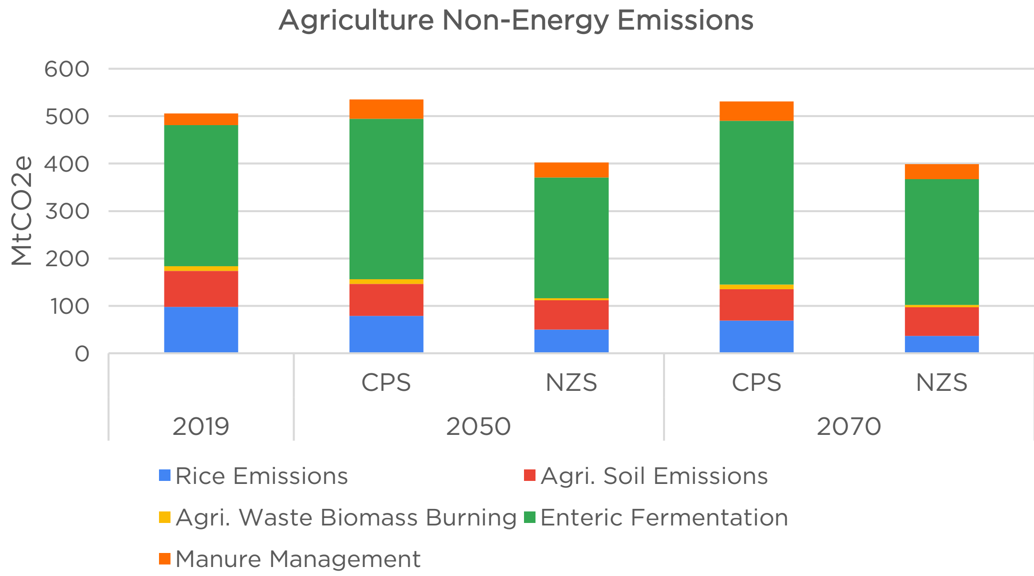
Two pathways: Current Policy Scenario and Net Zero Scenario are assessed; emission reductions ("mitigation co-benefits") are evaluated over time across nine key areas.

Figure 5.15 shows projected non-energy emissions from agriculture under two scenarios.

Current Policy Scenario: Total agricultural emissions are projected to increase from 506 MtCO_2e in 2020 to 531 MtCO_2e by 2070.

i. Rice methane emissions are projected to decline by ~30% by 2070 from its value in 2019 due to gradual adoption of sustainable practices like Alternate Wetting and Drying (AWD), System of Rice Intensification (SRI), and Direct-Seeded Rice (DSR).
ii. Soil N_2O emissions are projected to fall by ~12% from the 2019 value, because of better fertiliser use and growth in chemical-free/ natural farming.
iii. Livestock emissions are projected to increase by ~20%, driven by a rise in milk production, which offsets gains from improved breeds and nutrition.

Overall, Current Policy Scenario (CPS) shows modest progress in emission reduction, limited by slow adoption of resource-efficient practices and continued livestock expansion.



* *2019 emission reported in Third National Communication (TNC) were 421 MtCO$_2$e (estimated using AR-2 method), converted using AR-5 method in above chart*

Figure 5.15: Non-Energy emissions from agriculture sector under Current Policy Scenario (CPS) and Net Zero Scenario (NZS) by 2050 and 2070 (Million Ton CO$_2$e)

Net Zero Scenario: Presents a more ambitious path, with total emissions falling by ~21% by 2070, offering a 25% reduction compared to CPS. Importantly, this reduction is achieved through interventions that primarily strengthen agricultural resilience, with emissions mitigation delivered as a co-benefit rather than the primary objective.

i. Rice methane emissions are projected to reduce by 62% in 2070, driven by crop diversification, yield improvements, and widespread adoption of sustainable rice practices.

ii. Soil N_2O emissions are expected to reduce by ~20%, as compared to 2019, supported by large-scale chemical-free farming and improved fertiliser efficiency (up to 50%).

iii. Livestock emissions are likely to fall by ~8% by 2070 as compared to 2019, due to higher productivity (15 kg milk/day/animal) from genetic and nutritional upgrades.

System-wide transformation, combining technology, ecology, and demand-side shifts, can align India's agriculture with its Net Zero and resilience goals.

5.5.2 Agriculture Energy Use

Energy use in agriculture is estimated for two key services: 1) Irrigation pumping, and 2) Land preparation, including tillage and field operations using tractors and power tillers. Long-term energy demand for agriculture is assessed under the contrasting Current Policy and Net Zero pathways. Both share the same production outlook driven by population and dietary changes, with total crop output roughly doubling by 2070. However, they diverge in how irrigation and mechanisation needs are met, and in the pace of technology transitions, resulting in different energy use trajectories.

d. **Pump Irrigation Energy Consumption:** Energy demand for irrigation is estimated by converting water-pumping needs into useful energy and then final energy, accounting for efficiency improvements. Using data from the 5th Minor Irrigation Census (2017) and field studies, a typical irrigation pump is assumed to be 5-6 HP with a discharge of 20 m^3/h. Electric and solar pumps operate about 750 hours annually, while diesel pumps run only for 250 hours due to higher fuel costs. These assumptions yield a base-year stock of 20 million electric and 10 million diesel pumps, consistent with Minor Irrigation Census (MIC, 2017).

Under CPS, irrigation expands steadily: ~65% of GCA is irrigated by 2070, with groundwater supplying ~65%. Electric pumps dominate while diesel pumps decline slowly amid limited solar pump uptake. Average pumping head is assumed to rise from 28 m (2020) to ~50 m (2070) as aquifers fall. Pump-motor efficiency edges up to ~40% (diesel/electric), with solar comparable to electric.

In contrast, Net Zero Scenario (NZS) envisions a more efficient and sustainable irrigation system. The irrigated share of GCA stabilises near 60%, with reduced groundwater dependence (60%) owing to improved canal systems and aquifer recharge. Widespread adoption of efficient irrigation technologies (drip and sprinkler systems) improves water productivity by about 25% compared to 2019 levels. Diesel pumps are fully phased out by 2035, replaced by high-efficiency solar and electric pumps that achieve 50% efficiency by 2070. The average pumping head remains moderate at 35 metres, supported by better water management and recharge measures.

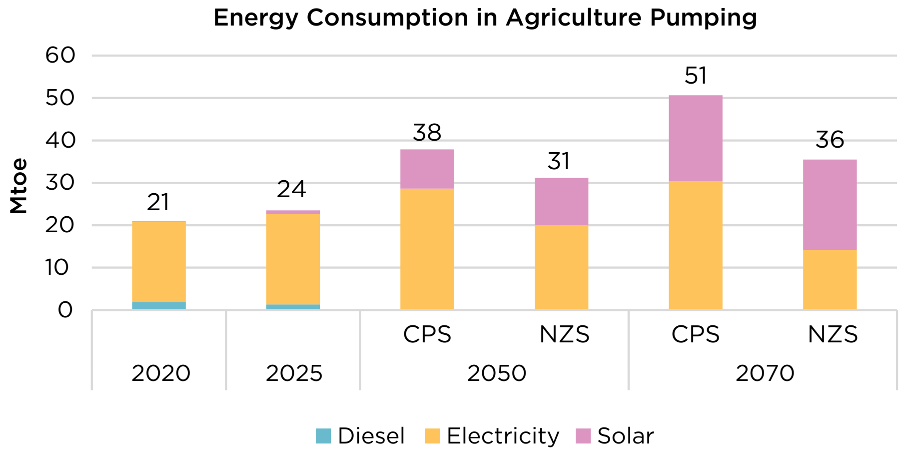


Figure 5.16: Energy demand and fuel mix in agriculture pumping under Current Policy Scenario (CPS) and Net Zero Scenario (NZS) by 2050 and 2070

India's irrigation pumping consumed around 21 Mtoe in 2020, with diesel accounting for about 10% of the total. By 2070, this demand is projected to rise to 51 Mtoe under Current Policy Scenario (CPS) and 36 Mtoe under the Net Zero Scenario (NZS) (Figure 5.16). Diesel pumps are phased out after 2040 in the CPS and by 2035 in the NZS.

Consequently, by 2070 the CPS fuel mix is 60% electricity and 40% solar, while in the NZS it is 40% electricity and 60% solar, reflecting faster clean-energy adoption.

e. **Land Preparation Energy Consumption:** Land preparation energy demand is linked to India's Gross Cropped Area (GCA), as each hectare requires preparation every season. The GCA was 185 Mha in 2019-20 and is projected to increase to 218 Mha by 2050 and 226 Mha by 2070. With the current mechanisation level of 47%, about 93 Mha were prepared using tractors or tillers in 2020, with the remainder relying on traditional methods. Mechanised preparation is dominated by tractors. Power tillers remain important for smallholder farms as over 85% of farmers own less than 2 ha, and tillers are cost effective for fragmented plots.

The energy demand is estimated using operating hours per hectare and fuel consumption by equipment type: tractors require fewer hours per hectare but consume more fuel per hour, while power tillers operate longer hours but use less fuel. These factors yield per-hectare energy intensities for both technologies.

Under CPS, energy demand is projected to rise to 2.1 Mtoe in 2020 to 3.8 Mtoe in 2050 and 3.3 Mtoe by 2070, with 9% diesel and 8% CNG required even by 2070. Efficiency gains and precision agriculture reduce per-hectare fuel use, but expanding mechanisation drives overall demand.

Under NZS, total energy demand is expected to stabilize at ~2.5 Mtoe by 2070 despite full mechanisation. Diesel is fully phased out by 2070, replaced by electric tractors and tillers. CBG sourced from crop residues and animal waste acting acts as a transitional fuel in the 2040s. By later decades, electric tractors dominate, offering ~30% higher efficiency and integration with a decarbonised grid and solar charging.

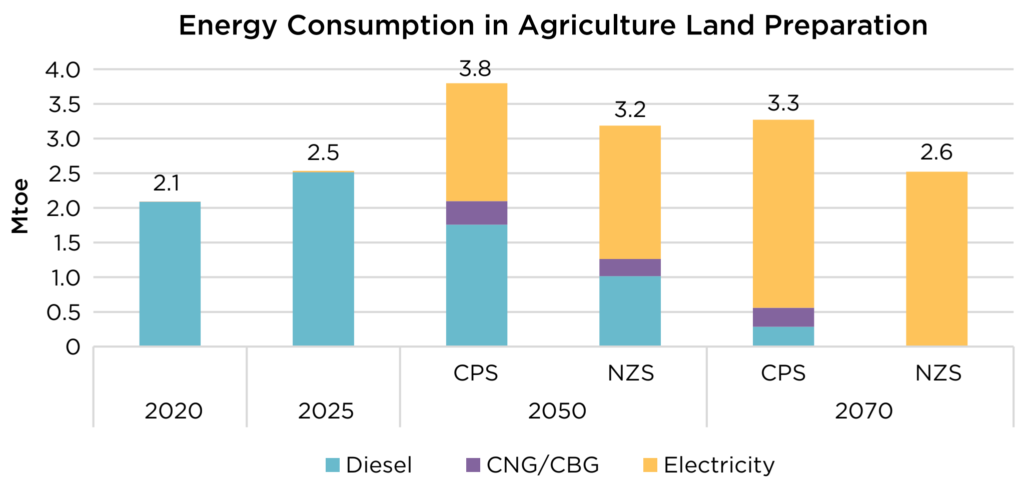


Figure 5.17: Energy demand and fuel mix in agriculture land preparation under Current Policy Scenario (CPS) and Net Zero Scenario (NZS) by 2050 and 2070

India's agricultural energy transition depends critically on the sequencing of efficiency measures and clean-energy adoption. Substituting diesel/grid pumps with solar reduces emissions but may not lower total energy use if irrigation volumes continue to rise; under current policies, pumping demand increases with deeper aquifers and expanding irrigated area. An efficiency-first approach coupling solarisation with micro-irrigation (drip/sprinkler) and daytime irrigation scheduling can reduce water (and thus energy).

5.5.3 Challenges and Suggestions

Agriculture and allied sectors (including livestock) are unique in India's climate context. They account for a significant share of emissions yet are highly vulnerable to climate change and tightly tied to livelihoods and food security. Unlike energy or industry, emissions here come from millions of dispersed producers and biological processes, making them harder to control. At the same time, most Indian farmers are smallholders, for whom yields and income are naturally the biggest priority. Given the sector's structural constraints and dependent livelihoods, there is a clear need for an adaptation-first framework delivering mitigation as co-benefits.

1. Crop Diversification

Challenge: India's food security has long depended on rice and wheat, particularly in Green Revolution states. Despite the Crop Diversification Programme under Rashtriya Krishi Vikas Yojana (RKVY) 2015 onwards, rice acreage remains high. Over-dependence on water-intensive paddy contributes to methane emissions, groundwater depletion, and soil stress.

Suggestions:

i. **Encourage supply-side diversification** by promoting pulses, millets, oilseeds, and horticulture, leveraging flagship government missions and budget commitments. Prioritise water-stressed, low-yielding regions where nutri-cereals are already grown.

ii. **Create demand-side linkages and diet diversification:** Integrate pulses and millets into the Public Distribution System (PDS) under the National Food Security Act (NFSA**)** to give farmers assured markets while reshaping consumption.

iii. **Align food welfare schemes**: Production shifts must be matched by changes in the food items supplied through welfare schemes, so that diversification crops actually reach households.

2. Rice Water Management

Challenge: Methane from rice is produced mainly from continuously flooded fields. Even as rice yields rose ~14% from 2011–2019 without acreage expansion, irrigated high-yielding rice in major states remains predominantly flooded, sustaining methane and groundwater stress. Some water-scarce states have shifted toward Alternate Wetting and Drying (AWD) and aerobic rice, but uptake is uneven.

Suggestions:

i. Scale AWD and aerobic rice where agro-climatic conditions permit, drawing on experience from states already applying these practices.

3. Nutrient Management

Challenge: Nitrous oxide (N_2O) emissions from soils are driven by nitrogen fertiliser use and rising cropping intensity. Fertiliser application averages of ~140 kg/ha per cycle indicate heavy nitrogen use. Between 2011 and 2019, cropping intensity rose from 139% to 151%, while Nitrogen Use Efficiency (NUE) continued to decline. This raises both emissions and input costs.

Suggestions:

1. **Expand precision fertilisation** through the Soil Health Card scheme, site-specific nutrient management, and techniques like deep urea placement and fertigation.
2. **Improve fertilizer quality** by scaling neem-coated urea and closely monitor the rollout of nano urea.
3. **Promote balanced nutrient use**, restoring phosphorus and potassium application alongside nitrogen to correct imbalances.

4. Natural and Chemical-Free Farming

Challenge: India's productivity gains have relied on synthetic fertiliser expansion and high-yielding varieties. While this has stabilised emissions relative to production, it has caused soil degradation, falling Nitrogen Use Efficiency (NUE), and water stress. Initiatives such as the National Mission on Natural Farming (NMNF), Paramparagat Krishi Vikas Yojana (PKVY), and Bharatiya Prakritik Krishi Paddhati (BPKP) promote natural farming, but adoption remains below 3% of cropland. Scaling is slowed by uncertain yields during transition, weak value chains for inputs and outputs, and limited certification systems.

Suggestions:

- i. **Target hotspots** using agronomic (fertiliser intensity), biophysical (soil health, rainfall, water stress), and socio-economic (SHG/FPO presence) criteria.
- ii. **Adopt context-specific scaling** in rainfed areas to raise yields and resilience; in Green Revolution belts to restore soils and aquifers. Rollout should be staggered and state-specific.
- iii. **Develop value chains** via Biodiversity Resource Centres (BRCs) for bio-inputs and training; link organic/natural produce to reliable procurement and marketing systems.
- iv. **Strengthen certification systems** to secure consumer trust, ensure price premiums, and protect farmers from unstable markets.

5 Livestock and Manure Management

Challenge: Livestock contributes ~60% of agricultural emissions, mostly methane from enteric fermentation. Between 2011–2019, milk production rose 55%, while emissions increased only ~2%, due to higher productivity and herd restructuring. Yet, average productivity remains below global levels, and rising milk demand could raise emissions and fodder pressure.

Suggestions:

- x. **Improve breeds** through scaled crossbreeding, artificial insemination, and IVF adapted to local conditions.
- xi. **Enhance animal nutrition and health** by addressing fodder deficits, promoting silage-making, and improving feed quality.

xii. **Increase feed efficiency** by raising protein content in diets to reduce methane per litre of milk.

xiii. **Adopt better manure management** through household and community-level biogas digesters.

6. Systems and Governance Approaches

Challenge: Scaling interventions in isolation risks counterproductive trade-offs. Balancing food security, nutrition, environment, and livelihoods requires an integrated governance approach.

Suggestions:

i. **Develop calibrated, intervention-specific roadmaps** for crop diversification, natural farming, and livestock productivity, grounded in economic, environmental, and social feasibility and sequenced geographically.

ii. **Adopt an agri-food systems approach** linking production, processing, distribution, consumption, and waste, so nutrition, environment, and livelihoods progress together. Operationalise through district-focused programmes e.g., Pradhan Mantri Dhan Dhaanya Krishi Yojana (PMDDKY) type designs that align production, diets, climate-resilient seeds, irrigation, and post-harvest infrastructure.

5.6 WASTE

Waste sector emissions include emissions from solid waste management and from domestic and industrial wastewater. In 2020, the sector accounted for just 2.56% of India's total GHG emissions, but its emissions have risen by over 7.3% between 2011 and 2020, driven by population growth, urbanisation and higher waste generation. Wastewater treatment and discharge contributed to 74% of the sector's emissions, while solid waste disposal contributed 26%. Methane (CH4) is the dominant gas emitted across both streams.[x]

India's urban population is projected to reach 51% by 2047, up from 37% in 2023. This rapid urbanisation, combined with population growth, economic expansion, and changing consumption patterns, will significantly increase municipal solid waste (MSW) and wastewater volumes, further intensifying emissions.

i. **Solid Waste:** India generated about 100.9 MT of solid waste in 2020, of which 61% was landfilled and the rest treated, processed, or incinerated. Of the processed waste, 28.5% was composted, 0.9% bio-methanated, 0.02% converted to bio-CNG, 0.5% recycled, and 2.8% incinerated (including RDF and pelletisation).

ii. **Domestic Wastewater:** In 2020, India generated 77,256 Million Litres per Day (MLD) of urban and 143,917 MLD of rural wastewater. Rapid population growth and urbanisation are driving this increase, while inadequate infrastructure hampers collection and treatment. In rural areas, only 3% of households have sewer connections, 36% use septic tanks, and 25% rely on pit latrines. In urban areas, 47% households use septic tanks, 33% are connected to sewers, and 55.1% of collected sewage remains untreated. Among treatment facilities, 63.75% use aerobic processes and 36.25% use anaerobic treatment.

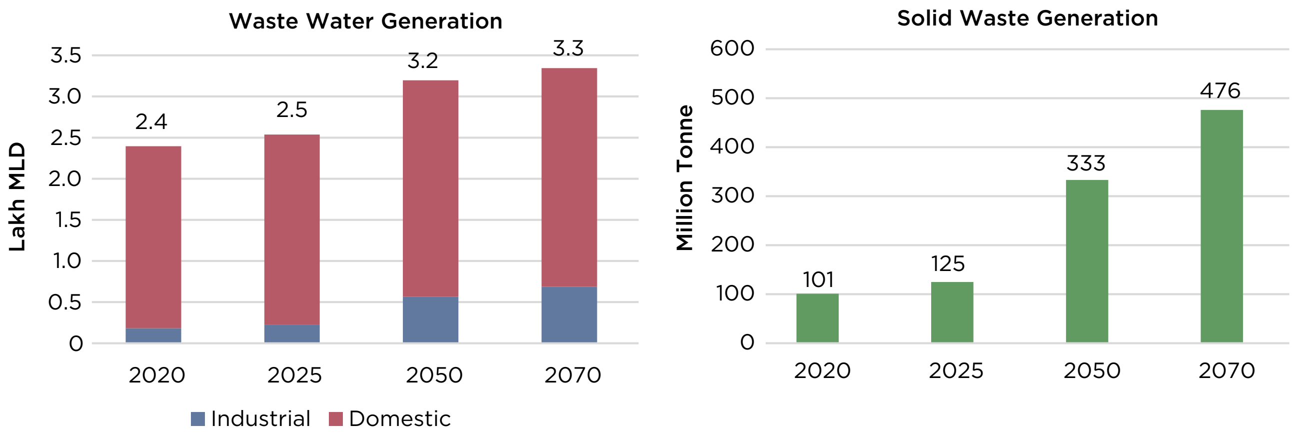
iii. **Industrial Wastewater:** India generated about 18836 MLD of industrial wastewater in 2020 (estimate-based) with more than three-fourth contributed by pulp & paper (43%), dairy (18%), and fertiliser (17%) segments.

5.6.1 Waste Generation and Emissions

Solid waste: India's solid waste is projected to rise from 100.9 MT in 2020 to 476.2 MT by 2070 (CAGR ~3.2%), driven by rapid urbanisation, population growth, and changing consumption with urban areas accounting for most of the increase (Figure 5.18b).

Domestic Wastewater: India's domestic wastewater generation is expected to rise from 221,173 MLD in 2020 to 265,791 MLD by 2070, (see Figure 5.18a). Urban wastewater will grow from 77,256 MLD to 171,938 MLD, while rural wastewater will decline from 143,917 MLD to 93,853 MLD due to falling rural population shares (from 65% to 35%). This shift eases rural infrastructure pressure but calls for major investments in urban sewer networks and treatment facilities.

x ICLEI South Asia. Low Carbon Action Plan for the Waste Sector of Bihar. 2023. Available at: https://southasia.iclei.org/wp-content/uploads/2024/05/Bihar-LCAP-Waste-Sector-Report_Combined_low-res.pdf (accessed 08 September 2025).



Figures 5.18a & 5.18b: Wastewater generation (domestic and industry) projections in India, projected solid waste generation in India

Industrial wastewater: Industrial wastewater is projected to rise sharply by 2070, driven by growth in sectors such as dairy, petroleum, sugar, fish processing, textiles, paper and pulp, fertilisers, and meat (Figure 5.18a). These industries generate high organic wastewater and methane emissions, highlighting the need for efficient treatment technologies and sustainable wastewater management.

These projections underscore the need for stronger infrastructure and policy to manage rising waste and wastewater. Emissions modelling for the sector uses Current Policy Scenario (CPS) and Net Zero Scenario (NZS) to guide its strategies and activities.

CPS projects outcomes from 2020–2070 under existing measures and gradual efficiency gains. By 2070, urban solid waste is expected to be 85% processed and 15% landfilled; rural is 50/50, with urban open burning phased out after 2030. Sewer coverage is likely to reach ~65% in urban and ~50% in rural areas. Wastewater treatment plants improve efficiency, achieving ~10% methane recovery. Industrial wastewater emissions remain broadly flat due to limited technology shifts.

The NZS aligns with India's 2070 Net Zero goal, prioritising circularity and low-carbon technologies. Urban per-capita waste is expected to stabilise after 2040; bio-methanation and bio-CNG expand significantly. Sewer coverage targets ~85% in urban/60% in rural; while STPs undergo full upgrades, achieving 100% methane recovery from anaerobic systems by 2047. Industrial wastewater moves towards near-zero methane via improved aerobic treatment and enhanced recovery from anaerobic units.[xi]

Based on these assumptions to model two scenarios, waste sector emissions are projected to be lower by 95.9% in Net Zero Scenario (NZS) compared to Current Policy Scenario (CPS), reaching 10.9 $MtCO_2e$ by 2070, as shown in Figure 5.21. The largest reduction is expected from industrial wastewater (49.4%), followed by domestic wastewater (37%) and solid waste management (13.6%).

xi These assumptions are further elaborated in the detailed sectoral report on the Waste Sector – Volume II.

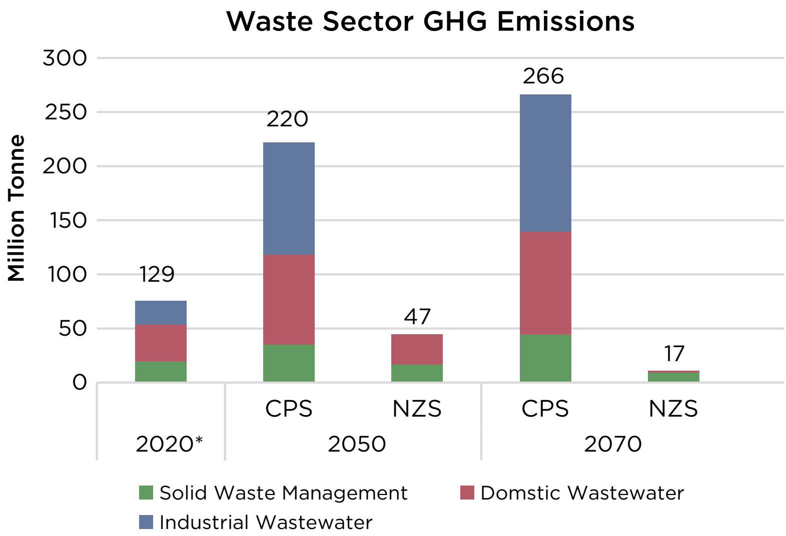


Figure 5.19: Projected emissions from waste sector by 2050 and 2070 under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

To move towards a Net Zero future, India will need to focus on continuously revising its Net Zero strategies to address residual/remaining emissions from the waste sector. It is crucial to acknowledge that the level of effort outlined in the NZS requires adaptation measures, substantial policy support, enabling frameworks, overcoming implementation barriers, capacity building, and financial support from city, state, and national governments, and the international community.

5.6.2 Challenges and Suggestions

India's waste sector sits at the intersection of urbanisation, public health, resource efficiency, and climate mitigation. While policy intent has strengthened over the past decade, implementation on the ground remains uneven. The challenges span the full waste lifecycle-generation, segregation, collection, processing, treatment, disposal, and are compounded by data gaps, financing constraints, behavioural barriers, and institutional capacity limitations. Addressing these challenges is critical not only for environmental outcomes, but also for India's pathway to Net Zero emissions and sustainable urbanisation.

1. Waste Generation and Handling

Challenge: India's solid waste and wastewater volumes are rising rapidly with urbanisation and changing consumption patterns, while engineered disposal space, sewerage networks and treatment capacity have to keep pace. Overburdened dumpsites, unsafe landfills, untreated sewage and weak faecal sludge systems can increase public health risks, pollute rivers/ groundwater, and lock in avoidable methane emissions. A key driver of poor outcomes can be limited source segregation, which contaminates recyclables and organics, undermines low-carbon processing (composting/bio-methanation), and reduces overall recovery value. The core challenge is not only infrastructure deficit, but also the sustained O&M capacity required to keep assets functional across diverse geographies.

Suggestions:

i. Reduce waste at source and strengthen circularity through Extended Producer Responsibility (EPR), eco-design incentives, eco-labelling, and the development of eco-industrial parks focused on recycling industries.

ii. Achieve 100% door-to-door collection, supported by waste quantification surveys to identify leakage (Swachh Bharat Mission 2.0).

iii. Strengthen primary collection by identifying the required workforce and vehicle capacities and deploying compartmentalised vehicles for segregated waste streams.

iv. Build/upgrade transfer stations where haul distances are high; minimise handling and add pre-sorting/decentralised Material Recycling Facilities (MRFs) where segregation is weak.

v. Expand sewerage wherever feasible to reach ~85% coverage, and deploy decentralised/on-site alternatives where centralised systems are not viable

2. Waste processing

Challenge: Scientific processing remains limited, informal recycling is under-integrated, and plastics leak into waterways and ecosystems. Emerging end-of-life streams (solar PV and batteries) can rapidly scale without traceability and recycling capacity, creating environmental risk and future material insecurity.

Suggestions:

i. Match processing choices to local waste composition and ensure adherence to standard norms to maintain efficiency, sustainability, and scalability.

ii. Expand composting and bio-methanation, prioritising bio-methanation where segregation is strong.

iii. Target ~85% Municipal Solid Waste (MSW) treatment through a portfolio approach , i.e., Bio-CNG, bio-methanation, composting for organics; MRFs for recyclables; Waste to Energy (WtE) only for non-recyclable dry/mixed waste sending only inert/process rejects to landfills.

iv. Achieve 100% treatment of collected wastewater by 2047; prioritise anaerobic systems with methane recovery targets.

v. Promote reuse of treated wastewater (agriculture, construction, horticulture).

3. Cross-cutting areas

Challenge: Capacity constraints, fragmented funding, and poor-quality, non-standardised data weaken planning, accountability and investment prioritisation.

Suggestions:

i. Continuous training for officials and operators (data protocols, digital tools, categorisation, QA/QC).

ii. Crowd-in private investment in processing, recycling, sustainable packaging and circular models; scale Sustainable Alternative Towards Affordable Transportation (SATAT) and GOBARdhan schemes with greater private participation.

iii. Strengthen behaviour change via MyGov/workshops/education and mainstream Mission LiFE.

iv. Integrate datasets (CPCB, MoHUA, NITI Aayog, NEERI, SPCBs) with standard methods and formats via a central digital platform. Enable transparency and third-party validation.

v. Mandate disaggregated reporting by local bodies (per-capita waste/wastewater, disposal pathways, and processing outcomes) to improve planning accuracy.

6

FINANCING NET ZERO PATHWAYS FOR INDIA

Financing Net Zero Pathways for India

6

6.1 BACKGROUND

Globally, finance for climate action rose to about USD 1.9 trillion annually in 2023 but remained well below the USD 6–9 trillion required annually to stay on a 1.5°C trajectory. Finance flows remain heavily concentrated with 80% flows to three regions namely East Asia, Western Europe, and North America, leaving South Asia and Sub-Saharan Africa dependent on limited public sources. Debt dominates these global flows, while adaptation and early-stage technologies continue to be underfunded.

In the Indian context, cumulative investment needs are estimated at USD 15–20 trillion by 2070, translating into USD 300-450 billion per year compared to annual flows of USD 135 billion in 2024 (of which only USD 70-80 billion supports clean energy). This large financing gap compounded by high capital costs, limited concessional finance, and structural constraints deter investment in India's low-carbon sectors.

While several studies assess climate finance needs, they differ in scope, methodology and time-horizon. India's transition spans technologies at different maturity levels. For instance, mature renewables need low-cost capital, and mid-stage options like storage and e-mobility require concessional or structured finance. Frontier areas such as Green hydrogen and Carbon Capture, Utilisation, and Storage (CCUS) depend on grants and blended capital. A stage-sensitive, technology-specific financing strategy is therefore essential.

This report addresses some of these limitations by developing a comprehensive assessment of investment needs, aggregate flows from domestic (Institutional capital, Banks/Non-Banking Financial Companies (NBFCs), Capital market), and foreign sources (Foreign Direct Investment, Foreign Portfolio Investment and External Commercial Borrowing) and assessing the financing gap at both aggregate and sectoral level. The study adopts an asset-flow model to estimate the likely availability of finance across sectors under a plausible set of enabling reforms.

In this study, the assessment was deliberately scoped to estimate the finance required to achieve India's Net Zero goal, and did not include detailed costing of climate adaptation measures. At the national level, the Ministry of Environment, Forest and Climate Change (MoEFCC) is currently leading the preparation of India's first comprehensive National Adaptation Plan (NAP) which will provide a strategic framework for identifying adaptation priorities and estimating financing needs for adaptation, consistent with Government of India and UNFCCC guidance. Subsequent versions of NITI's study will incorporate adaptation cost assessments to present a more holistic view of financing requirements.

(Scenarios towards Viksit Bharat and Net Zero: Financing Needs (Vol. 9) examines these issues in depth, this chapter synthesizes the key findings from that detailed analysis.)

Caveat: The study estimates India's investment needs and projected capital availability across three key mitigation sectors–power, transport, and industry. The estimates presented are indicative in nature and are contingent on underlying assumptions and specific modelling choices, including technology pathways, policy trajectories, and cost parameters. The results should be interpreted as directional rather than definitive. Other mitigation-relevant sectors, including buildings, waste, etc. are not included in the current investment estimation but are included for energy and emission estimation. These sectors will be analysed and incorporated in subsequent iterations of the study to provide a more comprehensive investment assessment.

6.2 RESULTS

6.2.1 Investment Requirement for Net Zero

The study assesses the cumulative investment requirement at USD 22.7 trillion by 2070 in Net Zero Scenario, with the power sector accounting for more than half of the investment requirement to drive higher demand electrification and to meet this demand through low-carbon power sources. Out of the total cumulative investment, USD 8 trillion needs to be front-loaded by 2050 with almost USD 5 trillion needed in the power sector, as most of the low-carbon technologies require substantial up-front investment.

After 2050, the Net Zero pathway shifts from scaling proven technologies to deploying risk heavy technologies. Green hydrogen becomes central for hard-to-abate sectors, while CCUS and DAC, negligible before 2050, scale up. Although investments in renewables and T&D continue, their relative share declines as frontier technologies absorb a larger portion of capital, explaining the higher long-term investment requirement.

In comparison with other studies, the quantum of investment differs due to differences in scope, methodology and time-horizon, the sectoral pattern remains consistent: the power sector accounts for highest share in investment needs, followed-by transport and industry (See Figure 6.1).

Estimates of Incremental Investment Requirements: The study estimates cumulative investment at USD 14.7 trillion in Current Policy Scenario and USD 22.7 trillion in Net Zero Scenario. Therefore, there is an incremental requirement of USD 8.1 trillion needed for Net Zero which reflects the cost of accelerated low-carbon technology deployment, policy interventions, and system-level investments essential for aligning with the net-zero pathways. At a sectoral level, the power sector accounts for the largest share of the incremental requirement (about USD 4.5 trillion), followed by industry (USD 2.7 trillion), and transport (USD 0.9 trillion) (See Figure 6.2).

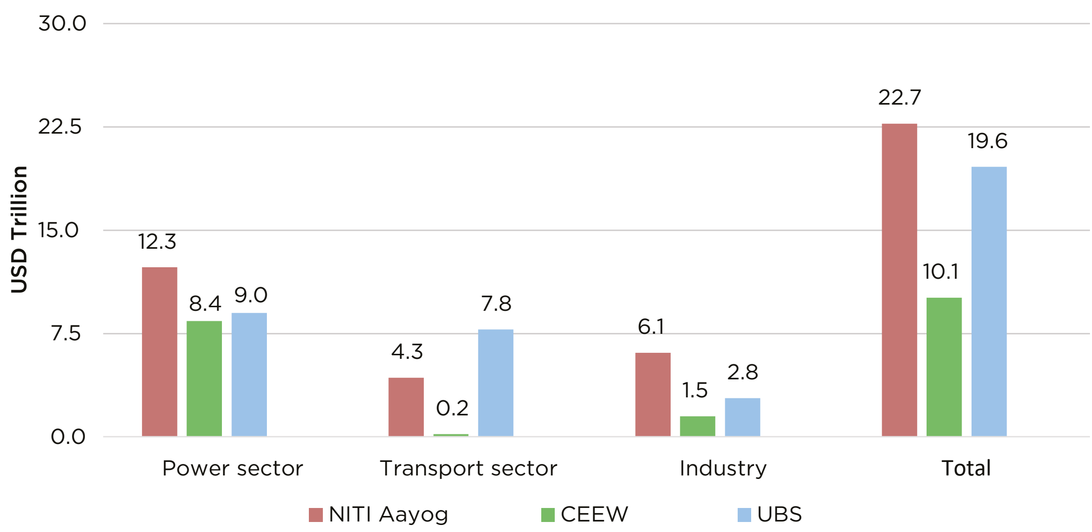


Figure 6.1: Estimates on cumulative investment requirements for Net Zero across various studies[xii]

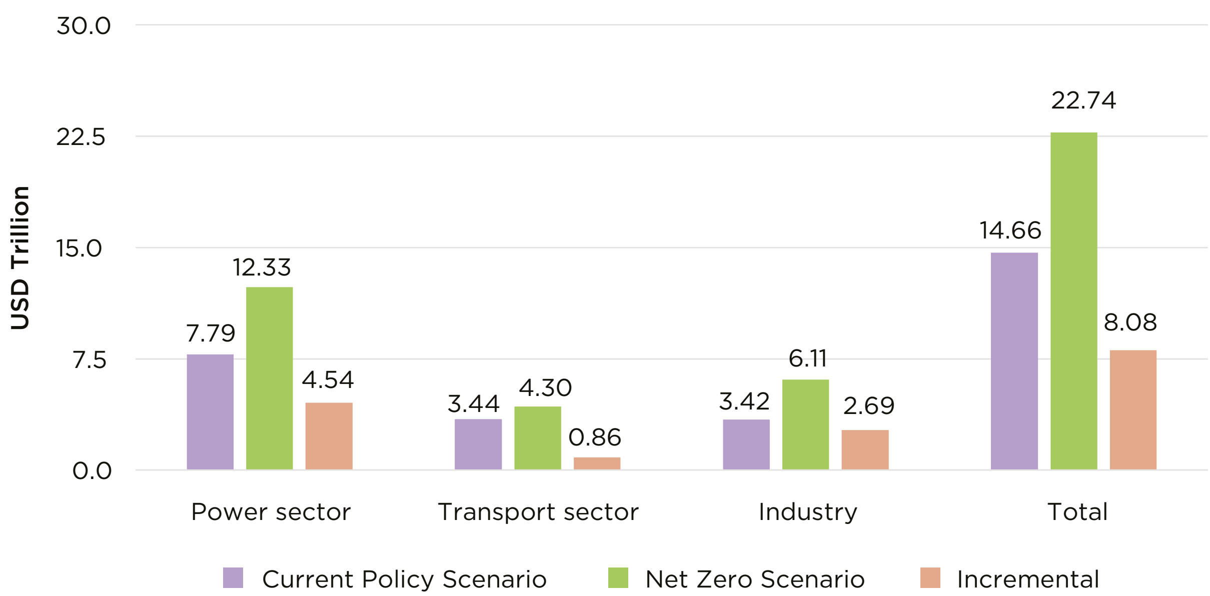
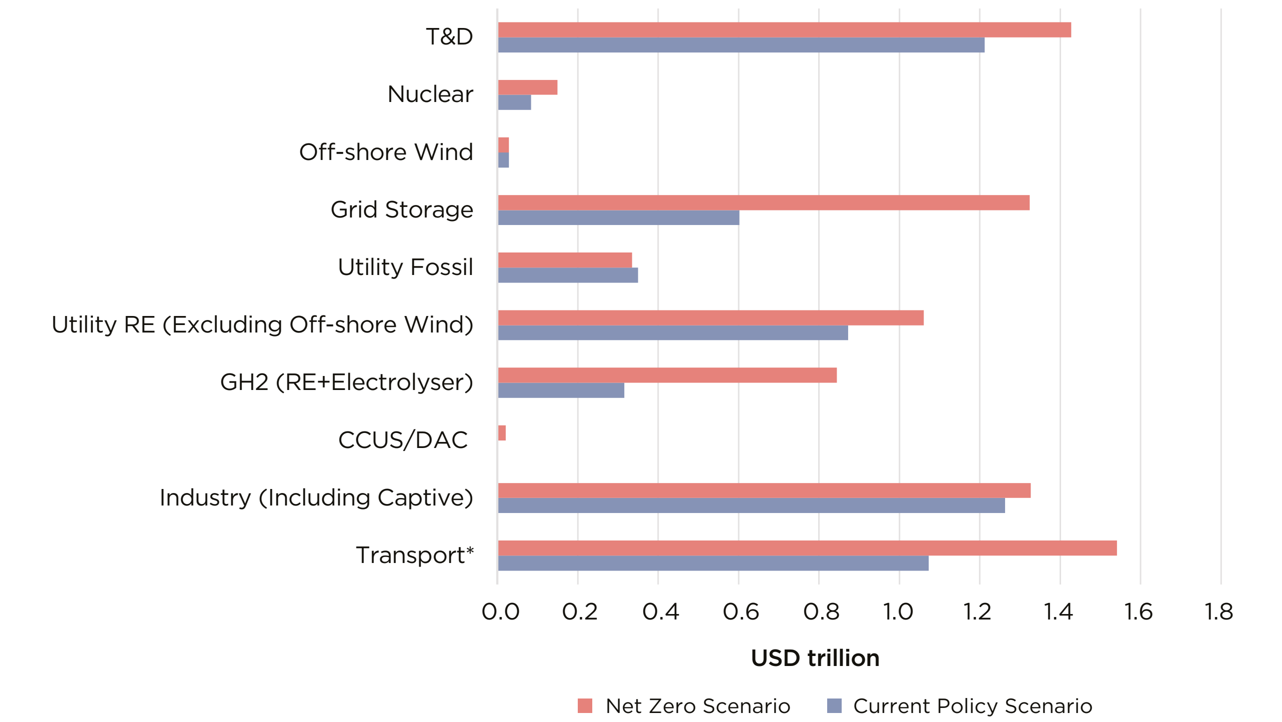


Figure 6.2: Sector-wise estimates of cumulative and incremental investment requirements for Net Zero by 2070

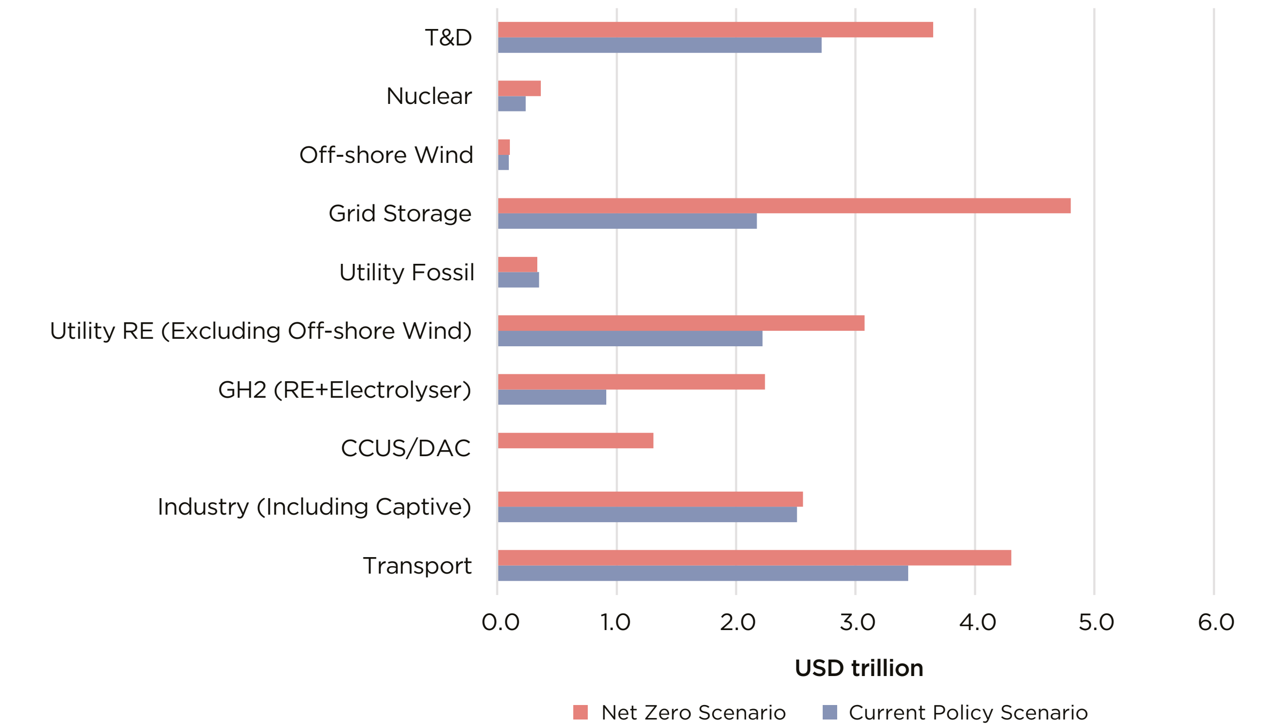
Technology-wise Investment Requirements: Up to 2050, the Current Policy and Net Zero pathways remains anchored in electrification and network buildout with the power sector accounting for more than half of the investment. The largest incremental differences with the Current Policy Scenario arise from higher investments in transport electrification, grid storage, and enabling infrastructure, reflecting the need to scale charging networks and system flexibility. By contrast, investment in frontier solutions such as Carbon Capture, Utilisation, and Storage

xii ***Note:*** *UBS estimates include Power–Renewable capex for utilities, Solar PV Manufacturing, Storage CAPEX from utilities, Transmission capex, overheads; Transport – EV battery capex from OEMs, EV battery manufacturing, overheads; Industry – Storage battery manufacturing, Associated equipment and systems, Green hydrogen, Electrolysers manufacturing, overheads.*

(CCUS), Direct Air Capture (DAC), offshore wind, and Small Modular Reactors (SMRs) remains limited by mid-century, underscoring that the near-term transition is driven primarily by scaling proven technologies rather than deep industrial transformation (See Figure 6.3).



(A)



(B)

Figure 6.3: (A) Total cumulative investment required (2025-2050): USD 8.1 trillion (NZS) vs USD 5.8 trillion (CPS) (B) Total cumulative investment required (2025-2070): USD 22.7 trillion (NZS) vs USD 14.6 trillion (CPS)

By 2070, the Net Zero investment requirements profile diverges sharply, marking a shift towards hard-to-abate solutions. Green hydrogen (including renewable capacity dedicated to electrolysers) emerges as a core pillar of the Net Zero pathway, absorbing a materially larger share of capital than under the Current Policy pathway and signalling its central role in promoting low-carbon transition in steel, refining, fertilisers, and long-distance transport. Carbon Capture, Utilisation, and Storage (CCUS) and Direct Air Capture (DAC), negligible before 2050, scale meaningfully only in the later decades, highlighting their role as backstop solutions for residual emissions rather than early levers. While investments in mature renewables and networks continue, their relative share declines as the transition increasingly depends on capital-intensive, technology and risk-heavy solutions, underscoring why post-2050 financing challenges are fundamentally different from those of the near term.

6.2.2 Availability of Investments

The previous sections estimated that India needs USD 22.7 trillion of investment for Net Zero pathway by 2070. It also estimated that there is an incremental finance need of USD 8.1 Trillion over the Current policy Scenario. This section looks at the availability of finance from both domestic and international sources.

Figure 6.4 shows the projected flows from various sources (domestic and international) mapped to end use sectors (power, transport, and industry). It also shows the various instruments (equity, debt, and bonds).

With coordinated reforms across domestic and external fronts, this study estimates that India can credibly mobilise around USD 16.2 trillion towards its Net-Zero transition by structurally expanding the scale, depth, and efficiency of capital. Domestically, this requires deepening the corporate bond market from ~16% of GDP in 2023 to ~30% by 2070, and increasing the financialisation of household savings from about 60% in 2023 to 75% by 2070. It also requires enabling institutional funds such as pensions and insurance to reduce their exposure to government securities from 55–60% to around 50% by 2070 while protecting investor returns through diversified, high-quality corporate and green assets. Externally, it needs scaling FDI to 3–4% of GDP and tripling Foreign Portfolio Investment (FPI) participation by 2047. This should be supported by credible transition roadmaps and a strong pipeline of bankable projects.

In terms of sources, banks and Non-Banking Financial Companies (NBFCs) continue to dominate, accounting for 42% of the total flows, followed by institutional investors and corporations (36%). In terms of instruments, the financing mix continues to be driven by equity (49%) and loans (45%) with a complementary role played by bonds. Across sectors, capital allocation continues to be concentrated in the power sector (43%), followed by industry and transport.

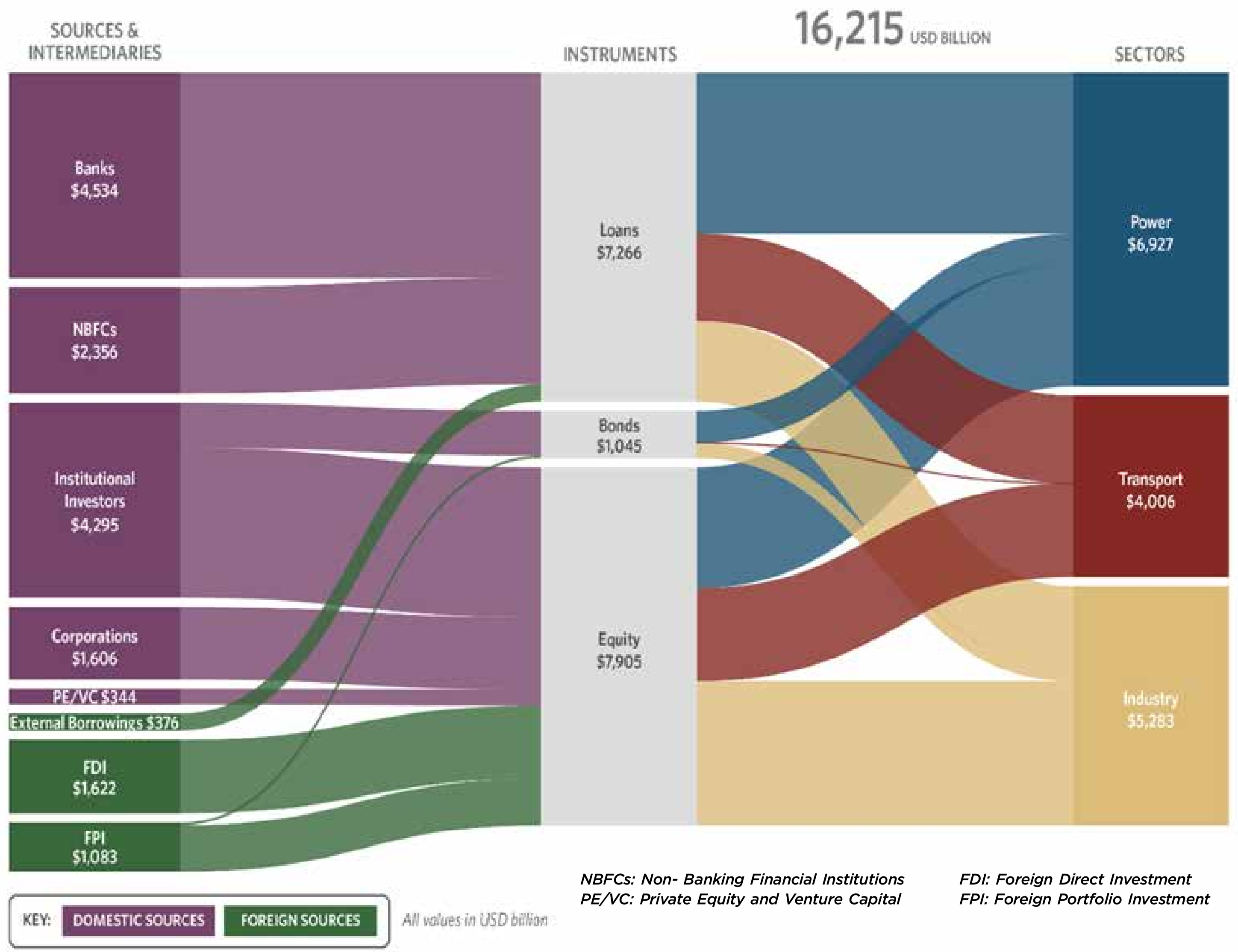


Figure 6.4: Projections of the sources and end use of finance supply for Net Zero (2026-70, USD billion)

Sectoral Analysis

The Power sector attracts the largest share of aggregate flows (USD 6.9 trillion) and is overwhelmingly domestically financed (~86%). Domestic banks and NBFCs are the dominant financiers, while foreign capital plays a smaller but still meaningful role, led mainly by FDI. The financing structure is debt-heavy, with loans accounting for just over half of total flows, followed by equity; bonds play a relatively limited role, indicating reliance on balance-sheet lending rather than capital markets.

The Transport sector accounts for USD 4.0 trillion, with a higher foreign share (~24%) compared to power, reflecting stronger participation of external investors. Domestic finance is still led by banks and NBFCs, while foreign inflows are significant. Unlike power, transport financing is split almost evenly between equity and loans, suggesting projects rely on project equity and bank lending.

The Industry sector absorbs USD 5.3 trillion and shows a more diversified financing mix. While domestic sources dominate (~77%), foreign capital is substantial, again largely via FDI. On the domestic side, banks and NBFCs remain important, but institutional investors play a nearly equal role, indicating deeper capital-market participation. Equity is the primary instrument (around 60%), with loans secondary, pointing to higher risk-sharing and growth-oriented financing relative to power and transport.

6.2.3 Assessing India's Net Zero Financing Gap

Against an investment need of USD 22.7 trillion for the Net Zero Scenario and estimated aggregate flows of USD 16.2 trillion, a financing gap of USD 6.53 trillion emerges, even with enabling measures on both the domestic and foreign fronts. Given that additional domestic finance remains scarce and that higher demand for domestic finance can crowd out investment and raise interest rates, thereby impacting economic growth, this financing gap is expected to be bridged by external sources. This raises the contribution of international sources to 42% of total capital needs by 2070, compared to 17% of flows from international sources in FY 2022–23. External capital therefore has a crucial role to play in India's Net Zero transition, especially in the form of concessional capital and grant to support technologies which are needed for Net Zero but are presently not commercially viable.

For 2026-2050, the financing gap is estimated at USD 2.5 trillion or USD 100 billion per year. The power sector remains the primary driver of this gap (~USD 80 billion per year), accounting for the bulk of investment requirements in renewable energy, transmission, and storage infrastructure. Industry and transport sectors also have a financing gap as they enter more capital-intensive phases of low-carbon transition.

For 2026-2070, the overall financing gap expands to USD 145 billion per year of additional investment (Figure 6.5). The power sector financing gap rises from USD ~80 billion per year till 2050 to 120 billion per year till 2070. The escalation reflects the intensification of low-carbon transition efforts across all sectors, led by the power sector's transition toward full renewable integration and large-scale storage. Industry faces growing costs from advanced technologies such as Carbon Capture, Utilisation, and Storage (CCUS) and green hydrogen, while transport's financing demand increases with the full rollout of EVs, clean freight, and sustainable fuels.

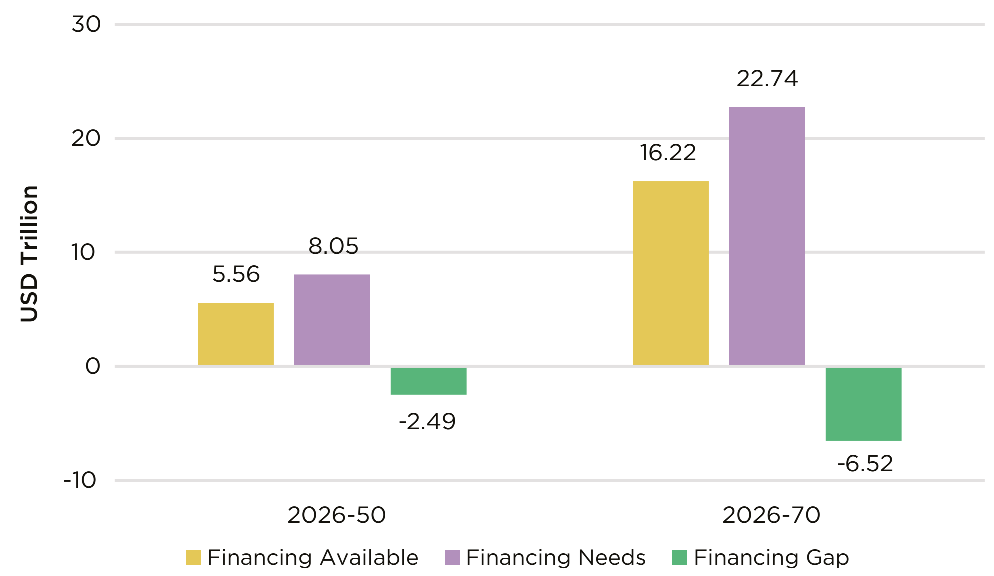


Figure 6.5: Projections of total needs, availability and gap (USD trillion)

Power sector: The analysis reveals a significant and widening financing gap in India's power sector as the country advances toward its Net Zero 2070 target. Till 2050, the cumulative financing needs for the power sector are estimated at USD 4.32 trillion, while available finance is projected at USD 2.34 trillion, resulting in a funding shortfall of USD 1.98 trillion. This gap more than doubles for 2070 needs, reaching USD 5.4 trillion, as cumulative financing requirements rise sharply to USD 12.33 trillion against an availability of USD 6.93 trillion (Figure 6.6). The expansion of this gap underscores both the scale of investment required and the structural challenges in mobilising long-term, low-cost capital for renewable energy, grid modernisation, and storage technologies.

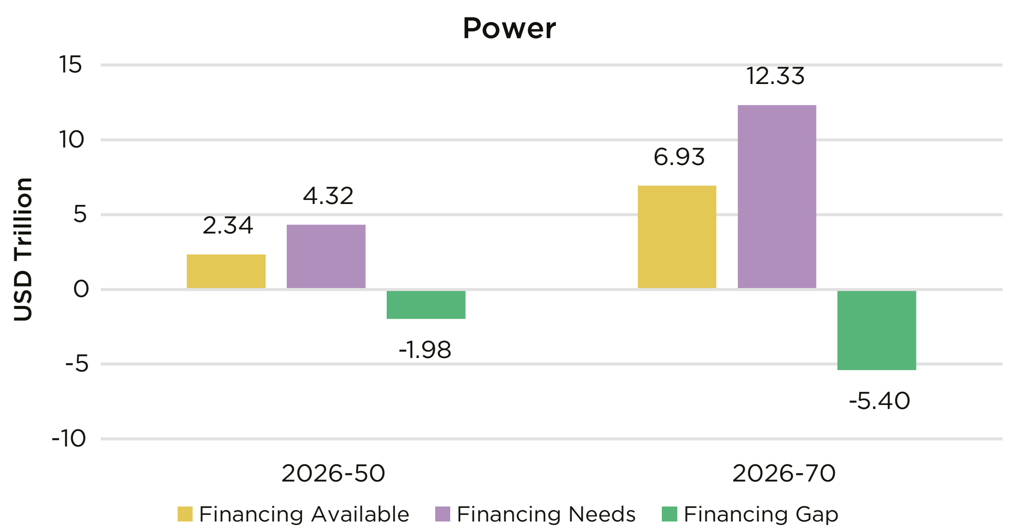


Figure 6.6: Power sector: Projections of total needs, availability and gap (USD trillion)

The substantial and growing gap also highlights the sector's heavy dependence on banks and NBFCs for debt financing, which are likely to face their own capital and exposure constraints over time. To meet its long-term financing needs, the power sector will need to diversify funding sources and increasingly tap bond markets and other capital market instruments to secure scalable, long-term debt capital. In addition, mobilising external sources of patient capital such as global sovereign wealth funds, pension funds, and other long-term institutional investors will also be critical to bridge the financing gap.

Transport sector: The transport sector shows a comparatively modest financing gap relative to other sectors, but its magnitude and implications are still significant given the sector's rapid growth trajectory. By 2050, cumulative mitigation finance needs are projected at USD 1.54 trillion, against USD 1.32 trillion in available financing, implying a shortfall of USD 0.22 trillion. This gap widens slightly by 2070, reaching USD 0.3 trillion, with cumulative financing needs increasing nearly threefold to USD 4.3 trillion, while available capital grows to USD 4.01 trillion (see Figure 6.7). Although the proportional gap narrows with time, the absolute financing requirements for low-carbon transition in India's transport system increase, reflecting the scale-up required in electric mobility, biofuels, hydrogen infrastructure, and electrification.

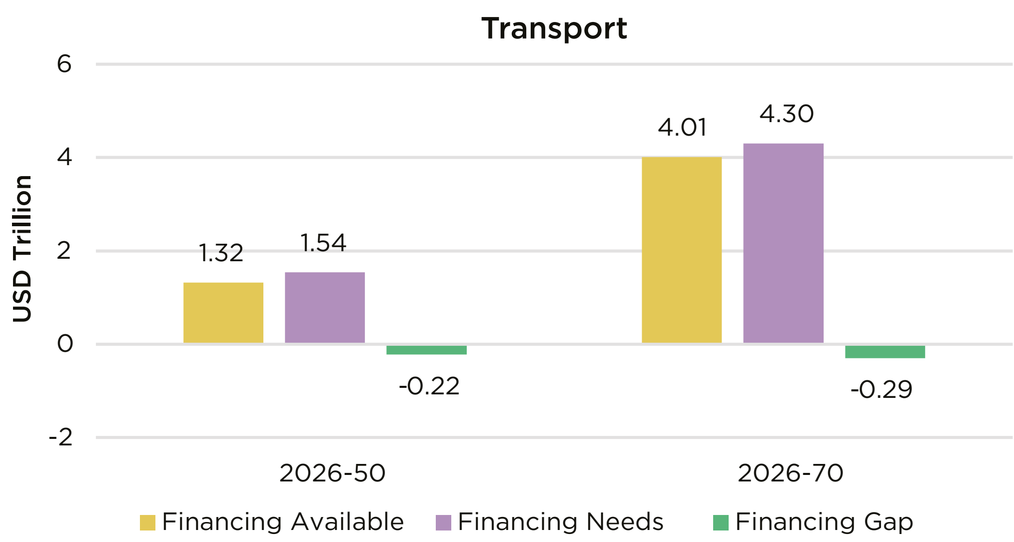


Figure 6.7: Transport sector: Projections of total needs, availability and gap (USD trillion)

Industry sector: The industry sector exhibits a growing financing shortfall with increasing decarbonisation needs. By 2050, cumulative financing requirements are estimated at USD 2.19 trillion, compared with USD 1.9 trillion in available finance, implying a financing gap of USD 0.3 trillion. However, by 2070, cumulative financing needs rise sharply to USD 6.11 trillion, while available capital is USD 5.28 trillion, widening the gap to USD 0.83 trillion (see Figure 6.8). This increasing shortfall reflects the mounting costs of transitioning India's hard-to-abate industries such as steel, cement, chemicals, etc. toward low-carbon technologies like green hydrogen, Carbon Capture, Utilisation and Storage (CCUS), Direct Air Capture (DAC), and electrified industrial processes.

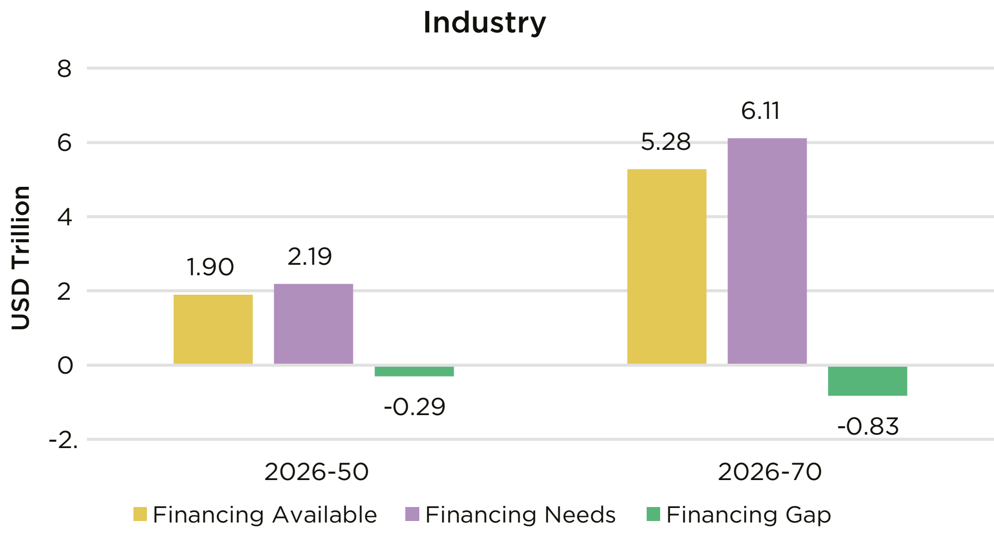


Figure 6.8: Industrial sector: Projections of total needs, availability and gap (USD trillion)

6.2.4 Challenges and Suggestions

Taken together, the results underscore both the scale and the structural complexity of financing India's Net-Zero transition. While coordinated reforms could significantly expand the availability of capital and mobilise substantial domestic and foreign flows, a persistent and widening financing gap remains across sectors. Moreover, the evolving investment profile from mature renewables in the near term to capital-intensive and risk-heavy frontier technologies in the long term implies that financing constraints are not merely quantitative but also qualitative, relating to risk allocation, cost of capital, tenor, and instrument suitability. These findings point to a set of systemic, market, and policy challenges that must be addressed to translate potential capital availability into actual, timely investments. The following section examines the key barriers to climate finance mobilisation in India and outlines targeted recommendations to bridge the identified gaps and enable a sustainable pathway to net zero.

1. Data, definitions, and transparency to build a credible data backbone

Challenge: India's transition hinges on transparent, comparable finance and emissions data. However, divergent methods, limited reporting, and uneven corporate reporting even with SEBI's Business Responsibility/Business Responsibility and Sustainability Reporting-Core[xiii] blur the real financing gap and weaken investor confidence.

Suggestions:

i. **Establish a unified national climate finance data platform** that tracks SEBI Business Responsibility and Sustainability Reporting disclosures, Carbon Credit Trading Scheme (CCTS) registry entries, and government finance. This will enable coherent tracking, facilitate cross-verification, and close persistent information gaps.

xiii BRSR refers to SEBI's Business Responsibility and Sustainability Reporting, introduced in 2021 for the top 1,000 listed companies by market capitalisation. BRSR-Core is the mandatory assurance component notified in 2023, requiring third-party verification of nine Key Performance Indicators (KPIs) covering emissions, energy, water, and supply-chain disclosures.

ii. **Mandate independent third-party assurance** at scale enforcing high-quality Measurement, Reporting, and Verification (MRV) under CCTS and instituting external audits for Climate Finance Taxonomy compliance.

iii. **Develop a sectoral Life Cycle Assessment (LCA) repository** to set science-based emissions baselines for key industries, support taxonomy thresholds, and strengthen the credibility of CCTS reporting.

2. Regulatory coherence and market signals to align to Department of Economic Affairs' Climate Finance Taxonomy

Challenge: India's climate finance regulations are being developed by multiple autonomous regulators (RBI, SEBI, IRDAI, PFRDA, IFSCA) with different lenses, timelines, and disclosure frameworks. This siloed approach risks inconsistent definitions, overlapping requirements, and regulatory arbitrage, which can amplify greenwashing risk, weaken market signals, and prevent a system-wide view of climate risk.

Suggestions:

i. **Adopt the Climate Finance Taxonomy** prepared by the Department of Economic Affairs (DEA) as the single reference system, aligning rules, disclosures, and prudential treatment across all regulators.

ii. Mandate cross-regulator harmonisation of definitions, data, and disclosures anchored to the taxonomy.

iii. Apply proportionality (risk-based, size-appropriate obligations) so that smaller entities face calibrated requirements without eroding credibility.

iv. Strengthen the existing working group mechanisms such as Finance Stability and Development Council (FSDC) and Sustainable Finance Group housed in RBI to address climate change and climate finance issues.

3. Building bankable project pipeline through Accelerating Sustainable State Energy Transition (ASSET) platform

Challenge: Deployment of investments at scale requires a pipeline of credible and bankable projects. However, several factors deter projects from achieving financial closure despite available liquidity. In the power sector, discom financial distress, weak creditworthiness, and uneven Power Purchase Agreement (PPA) enforcement elevate financing costs. Technologies such as offshore wind and energy storage lack mature risk-mitigation and refinancing instruments. In industry, high upfront costs and uncertain paybacks deter decarbonisation, especially for MSMEs that face credit constraints and limited access to blended finance and de-risking facilities. Transport finance is mode-specific and fragmented; private participation in metros and rail is limited, and EV adoption faces high capital costs. In buildings, small-ticket fragmentation, long paybacks, split incentives between owners and occupants, and weak enforcement of energy codes keep efficiency upgrades and retrofits outside mainstream finance.

Suggestions:

i. **Use ASSET platform for building a project pipeline:** Building on the National Infrastructure Pipeline (NIP) and National Monetisation Pipeline (NMP) playbook, it is important to identify high value clean energy projects and help them achieve financial closure with appropriate instruments. States are very important in design and implementation of clean energy projects.

Accelerating Sustainable State Energy Transition (ASSET) Platform

NITI Aayog, in collaboration with the Ministry of Power and the Ministry of New and Renewable Energy, launched the ASSET platform in November 2024. The platform is set-up with the objective of formulating state energy transition blueprints along with aiding in its implementation, preparing a pipeline of bankable projects and showcasing best practices across states.

ASSET can unlock early wins in many areas such as:

i. Urban Local Bodies (ULB) water-pumping upgrades through standardised energy audits, demand aggregation, and ESCO/RESCO models backed by pooled payment security.

ii. Scaling efficient air-conditioning by aggregating replacement demand and embedding high-efficiency appliances in new housing via green finance incentives (e.g., concessional developer finance, property-tax rebates, and green mortgages) alongside efficiency-code nudges.

iii. Electrifying municipal garbage truck fleets using aggregated procurement and risk-mitigation/structured finance to overcome high upfront costs and elevated financing rates driven by technology and residual-value risk.

iv. Financing Metro Systems through Transit-Oriented Development (TOD) and value capture.

v. EV adoption accelerated through anchor fleet contracts (logistics/e-commerce) and route-based aggregation to create predictable cashflows.

vi. Industries to adopt efficiency or renewable solutions through ESCO/RESCO models, which can be pooled to provide scale and combined with risk guarantee mechanisms to improve project viability for investors.

vii. Implement blended finance solutions to promote adoption of waste heat recovery, low-carbon process electrification, energy-efficient motors, and circularity.

ASSET is a recent initiative, its expansion should be phased with ASSET targetting early wins in areas where aggregation and standardised contracting can quickly improve bankability. This includes Urban Local Bodies (ULB) water pumping efficiency upgrades, high-efficiency cooling programmes, and electrification of municipal fleets. Any scale-up should be guided by a clear performance assessment framework and follow-on actionable recommendations, to avoid premature expansion and strengthen credibility with financiers.

4. *Cost of capital and technology readiness addressed by blending risk by stage*

Challenge: Climate transition is constrained as much by the cost of capital as by the availability of capital. The cost of capital stays high because investors price in sovereign risk alongside the additional uncertainty of new technologies. The result is a much higher Weighted Average Cost of Capital (WACC) than in advanced economies. Climate Policy Initiative's (CPI) study estimates investors seek about 15.9% returns on clean energy investment in India versus 8.3% in Germany. At these rates, big, early-stage bets in green hydrogen, CCUS, and hydrogen-based steelmaking struggle to reach financial closing unless they come with credible de-risking/blended finance to bring risk premia down.

Suggestions:

i. **Blended finance:** Deploy concessional/junior tranches, interest buy-downs, and subordinated equity to improve project credit profiles.

ii. **Credit wraps for First-of-a-Kind (FOAK) projects:** Use first or second-loss guarantees and performance/resource insurance (with Development Financial Institution/ Multilateral Development Bank participation) to crowd in senior lenders to hydrogen, CCUS, long-duration storage, and offshore wind.

iii. **Revenue certainty:** Standardise long-term Power Purchase Agreements and strengthen offtake credit enforcement.

iv. **Targeted support:** Use Viability Gap Funding (VGF) with sunset clauses and dedicated credit lines for near-commercial/emerging technologies; fund R&D/demonstration to build bankable operating histories.

5. *Bridging India's energy transition financing gap through domestic and external capital mobilisation*

Challenges: Current financial flows into India's energy transition fall well short of the scale required to meet future demand. The present study estimates that India will need approximately USD 22.7 trillion in cumulative investment by 2070 to achieve a successful transition covering both fossil and non-fossil sources. This translates to USD 450 billion annually, almost nine times higher than the current flow of around USD 50 billion (annual average of FY2020-22).

Suggestions:

i. **Domestic reforms to boost capital availability:**

   i. Deepening the corporate bond market from about 16% of GDP today to 25% by 2047 and 30% by 2070 through streamlined regulation, digitised issuance, improved liquidity, and a broader investor base.

   ii. Reorienting long-term institutional portfolios toward green and transition assets by reducing insurers' and pension funds concentration in government securities from around 55-60% to about 50% by 2047 and redirecting flows into high-quality corporate and green debt.

   iii. Mobilising household savings through transparent, low-risk products digitally linked to green infrastructure.

ii. **External reformsː**

   i. Proactively target long-term foreign capital including FDI, sovereign wealth funds, and global pension funds to supplement domestic pools and ease upward pressure on domestic borrowing costs. This requires establishing standardised co-investment platforms anchored in International Financial Services Centres Authority (IFSCA)/Gujarat International Finance Tec-City (GIFT City).

   ii. Scaling FDI from about 2.3% of GDP today to 3–4% by 2047 by enabling strategic technology partnerships, credible transition roadmaps, and a sustained pipeline of bankable projects.

   iii. Expanding foreign portfolio investment participation from around 0.5% to about 1.5% of GDP by 2047 by reducing currency risk through deeper FX markets, longer-tenor hedging instruments, and supportive regulatory access.

6. Transition finance to bridge brown-to-green credibly

Challenge: India's transition is not only about "pure green" assets, it also requires decarbonising carbon-intensive incumbents like steel, cement, coal-linked power, refineries, and heavy transport without constraining growth. In 2024, the IEA World Energy Investment report estimated India's total energy investment at USD 135 billion of which USD 87 billion is supporting clean energy. This highlights that even in the current context, there is significant investment in fossil assets which cannot be replaced overnight; transition finance is the bridge.

Suggestions:

i. **Clear rules & labels:** Operationalise IFSCA's transition framework and SEBI's Sustainability-Linked Bonds (SLBs)/Transition Bonds; align with the Department of Economic Affairs' Climate Finance Taxonomy (recognising transition activities).

ii. **Credible pathways:** Tie financing to time-bound, third party-verified transition plans with penalties for missed targets.

iii. **Fit-for-purpose instruments:** Use Transition Bonds and SLBs for specific brown-to-green actions (e.g., clinker substitution, DRI-H_2 pilots, waste-heat recovery).

iv. **Risk-sharing:** Lower costs via partial/first loss/second loss guarantees and FX hedging with MDB/DFI support to reduce pressure on domestic public balance sheets.

v. **Market plumbing & disclosure:** Extend Business Responsibility and Sustainability Reporting (BRSR) to cover transition plans and post-issuance reporting. Any inclusion of Scope 3 disclosures should be phased and proportional starting with large entities in high-impact sectors to avoid disproportionate compliance burdens on MSMEs and smaller suppliers.

7

MACROECONOMIC IMPLICATIONS OF NET ZERO TRANSITION

Macroeconomic Implications of Net Zero Transition

7

7.1 BACKGROUND

As emphasized in the previous sections, this report first discusses India's aspiration of becoming a developed economy, Viksit Bharat by 2047 with a growth target of USD 30 Trillion by 2047. The implication of this growth pathway across key energy consuming sectors such as Industry, Transport, Power, Buildings and Agriculture are assessed.

While meeting this developmental objective, the report extends the analysis by imposing an additional goal of achieving Net Zero greenhouse gas (GHG) emissions by 2070. This involves evaluating sector-specific technology and policy options required to deliver Net Zero outcomes. While several of these technologies are already commercially mature and cost-competitive, others such as Green Hydrogen, Small Modular Nuclear reactors, and Carbon Capture, Utilisation and Storage (CCUS) are at varying stages of development, with commercial viability expected to emerge over time as costs decline and deployment scales up.

In this context, a critical question that emerges is about reconciling the pursuit of a Net Zero pathway with India's growth aspirations. This question is particularly salient given that the primary objective remains the achievement of developmental goals, even as India contributes to addressing the global challenge of climate change. The potential risk of technological lock-in to capital-intensive or uncertain options, such as CCUS, and its implications for long-term growth warrants careful examination.

A rigorous, economy-wide assessment is therefore undertaken to examine the interactions between climate action, growth, investment, trade, and employment, and to identify potential trade-offs and synergies across sectors through two Computable General Equilibrium (CGE) modelling frameworks: the NCAER model and the World Bank's MANAGE model[xiv]. The implications are examined through the Current Policy Scenario (CPS) and multiple Net Zero Scenarios differing by financing sources, redistributive mechanisms, and productivity co-benefits.

In terms of financing sources, the scenarios explore two extreme scenarios wherein the total investment required is mobilized completely through domestic sources (NZdom) vs mobilized through foreign sources (NZfor)[xv]. Within these scenarios, the variation in terms of productivity co-benefits (represented through "+" scenarios) is also examined, i.e., whether additional investment from domestic sources is productive (NZdom+) or unproductive (NZdom). In a

xiv MANAGE-World Bank is a Computable General Equilibrium (CGE) model developed by a network of CGE modellers to support World Bank teams and clients in conducting macroeconomic analyses across a broad range of topics. It is a single-country, open economy CGE model featuring multiple sectors, institutions, and factors of production.

xv The two scenarios represent two extreme cases in which funding is either completely through domestic or foreign sources. These are theoretical constructs assumed for the purpose of modelling. Reality will be somewhere between these two extremes.

productive scenario, additional investment leads to productivity improvements and high economic output. The scenarios also examine redistributive policies wherein the impact on energy prices can be mitigated through energy subsidies. Together, these variants define lower and upper bounds for the growth implications of a Net Zero transition (see Table 7.1).

Table 7.1: Summary of Net Zero Scenarios using World Bank[xvi] and NCAER models

	Benefits from incremental investment in the Net Zero Scenarios		Main source of financing		Complementary measures to facilitate the transition	
	Emission reduction only	Output effect	Domestic	Foreign	RE subsidy	Redistribution
NZdom	✓		✓			
NZdom+	✓	✓	✓			
NZfor	✓			✓		
NZfor+	✓	✓		✓		
NZforSub	✓			✓	✓	
NZdomSub	✓		✓		✓	
NZforRD	✓		✓	✓		✓
NCAER				✓		

(Scenarios towards Viksit Bharat and Net Zero – Macroeconomic Implications (Vol. 2) examines these issues in depth, this chapter synthesizes the key findings from that detailed analysis.)

Caveat: These results exclude both negative externalities and positive co-benefits of climate change. The negative impacts include reduced labour productivity or agricultural losses from rising temperatures whereas the positive co-benefits include improvements in air quality and health outcomes, which the model does not capture.

7.2 RESULTS

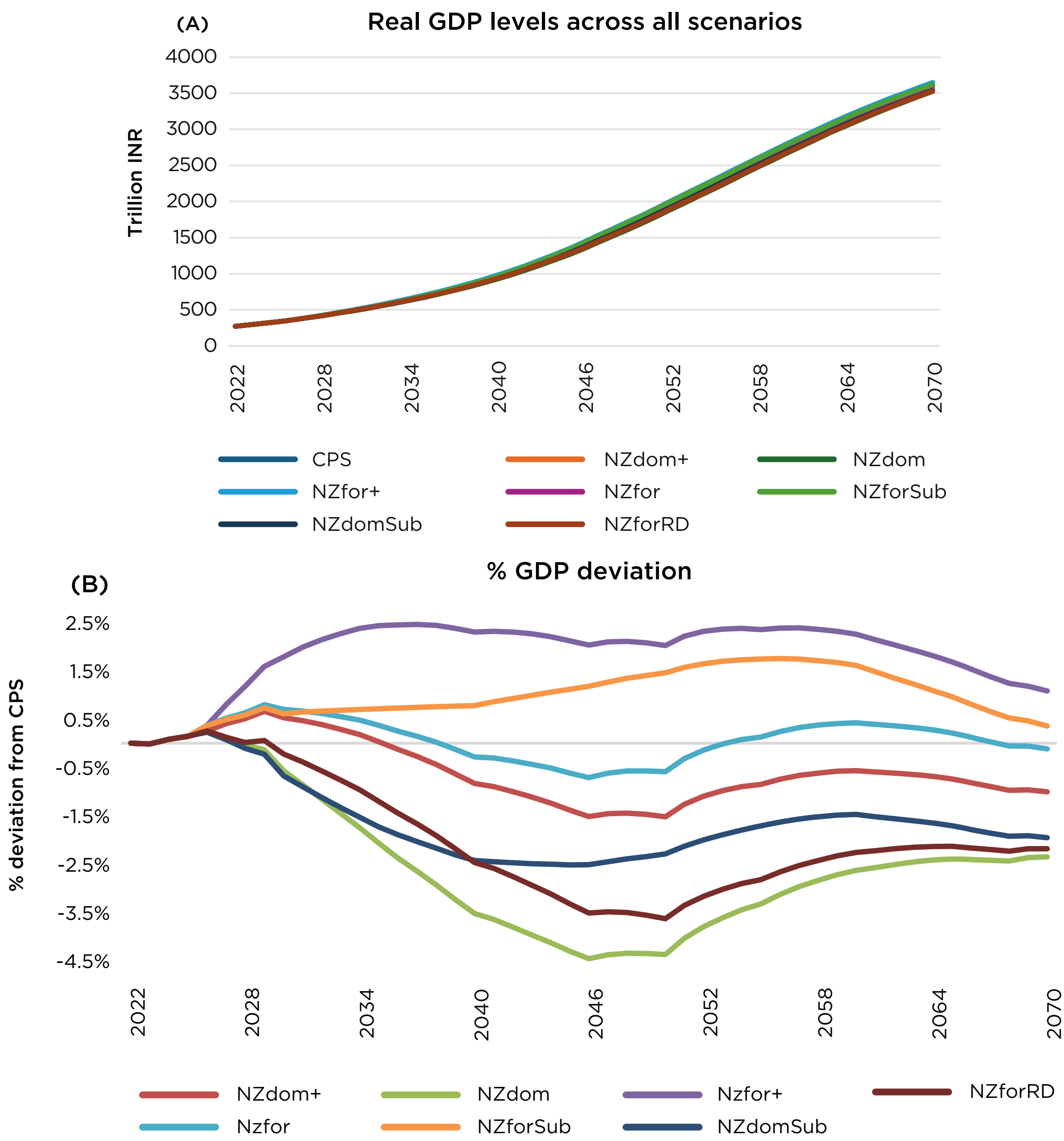
7.2.1 Impact on GDP

The results show that India's Net Zero Scenario (NZS) has only a marginal impact on long-term GDP growth but demands high investment and substantial capital mobilisation, particularly to scale up nascent and emerging technologies (Figure 7.1 (A)). Across all Net-Zero scenarios, GDP growth remains broadly aligned with the Current Policy Scenario (CPS). India achieves high-income status in 2047 (USD 30 trillion) across all scenarios.

While the impact on overall GDP in NZS vs the CPS is marginal, there exist subtle differences across scenarios depending on source of financing. As seen in Figure 7.1 (B), productive, foreign-

xvi The World Bank MANAGE model analyses seven Net Zero scenarios that vary by financing source, productivity of incremental capital and redistribution policies. NZdom and NZfor are financed through domestic savings and foreign capital, respectively; Sub variants add renewable energy subsidies to stabilise electricity prices; NZforRD includes redistribution to protect the bottom 40% of households; and "+" scenarios assume Net Zero investments generate productive output gains, representing upper-bound growth outcomes.

financed scenario (NZfor+) shows enhanced output (+2% during 2045-50 compared to CPS), while domestically financed scenario has a lower GDP by -4.5% as compared with CPS in 2046-50. These scenarios present two extreme cases of GDP change with other scenario results falling within this range.



Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 7.1 (A) Real GDP levels (trillion INR) (MANAGE model) (B) Net Zero Scenario GDP outcomes across financing channels (deviation from the CPS in %) (MANAGE model)

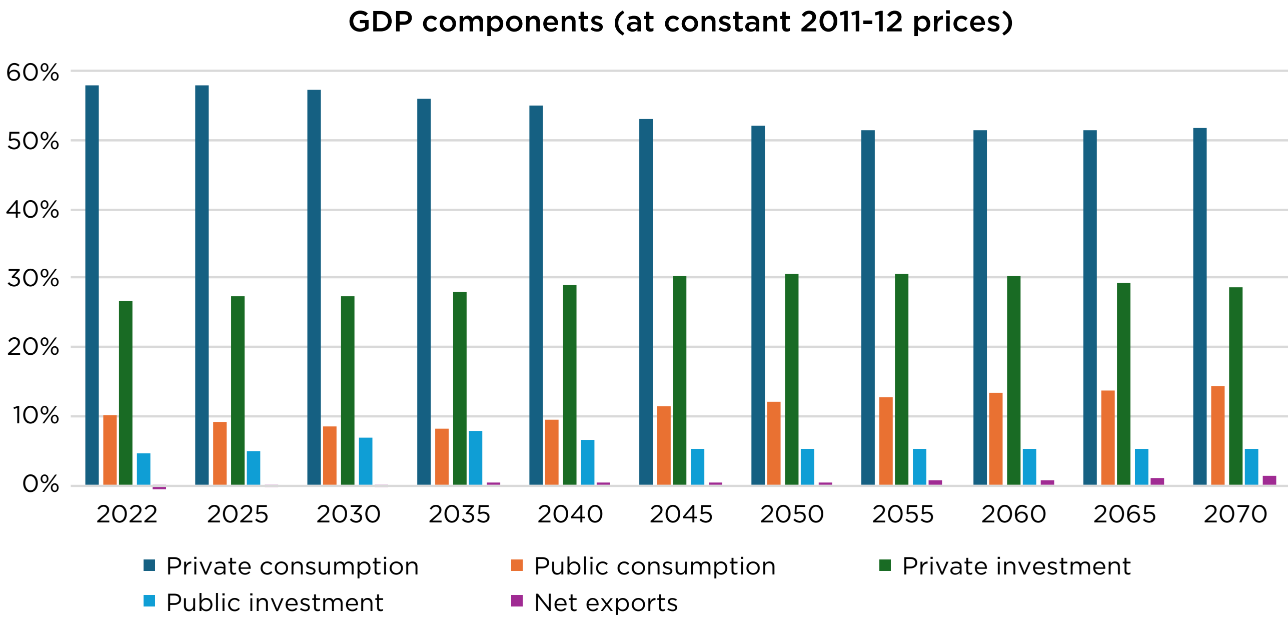
7.2.2 Impact on GDP components

As seen in Figure 7.2 (A), in Current Policy Scenario, private consumption's share in GDP is projected to reduce from 58% in 2025 to 49% in 2070. Total investment share (public+private) rises from 32% in 2025 to around 36% by 2050 and moderately reduces to 34% by 2070, a trend seen in other developed economies.

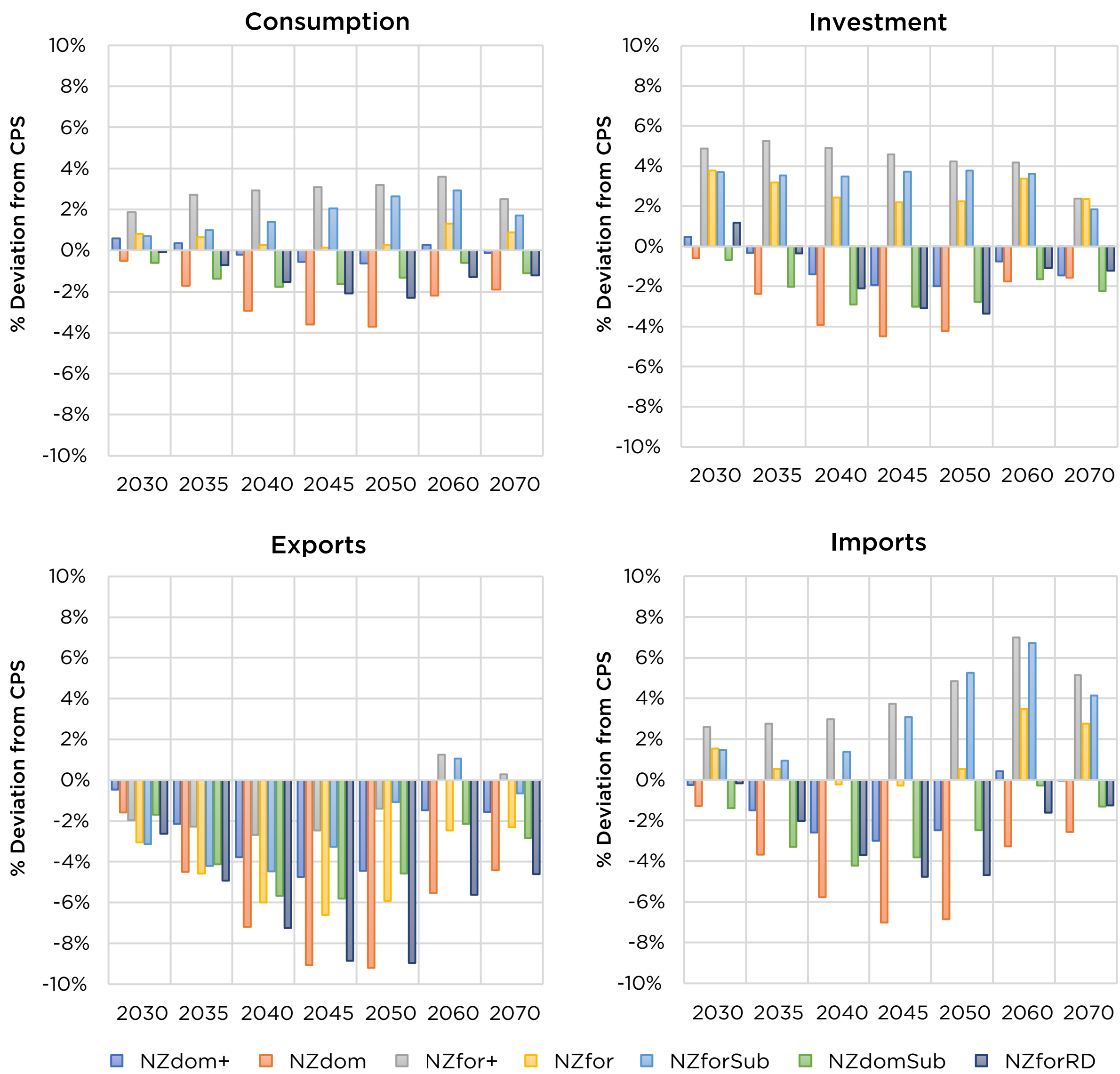
Net Zero scenarios relying on domestic financing (NZdom, NZdom+, NZdomsub) generally have a reducing effect on investment compared to Current Policy Scenario (See Figure 7.2 (B)). This is most pronounced between 2040 and 2050, when investment under NZdom is lower than the Current Policy Scenario by about 5%. In contrast, scenarios with external financing (NZfor, NZfor+, NZforSub, NZforRD) show higher investments. The main reason is the higher real interest rate under domestic borrowing which constrains access to affordable capital. Higher interest rates also encourage households to save rather than spend, reducing consumption in domestically financed scenarios. In the productive investment cases (NZdom+, NZfor+), however, higher household incomes outweigh the drag from higher interest rates, producing a net increase in consumption. Therefore, in Net Zero scenarios, domestic financing leads to tightened liquidity, pushing up interest rates and crowding-out consumption, whereas foreign financing eases interest-rate pressures and supports higher investment.

India's transition to high-income status is accompanied by rising trade volumes, with exports and imports both increasing in absolute terms, while remaining broadly stable as a share of GDP (Figure 7.2 (C)) at around 23 - 25% under the Current Policy Scenario by mid-century. Differences across Net Zero pathways are driven largely by financing choices. Domestically financed scenarios show lower exports, reflecting higher domestic costs and tighter resource constraints, but these are offset by substantial reductions in fossil fuel imports, resulting in lower overall trade exposure. Foreign-financed scenarios moderate lowering of exports by avoiding crowding out and supporting higher investment, though they are associated with larger current account and trade deficits in the medium term due to higher capital inflows.

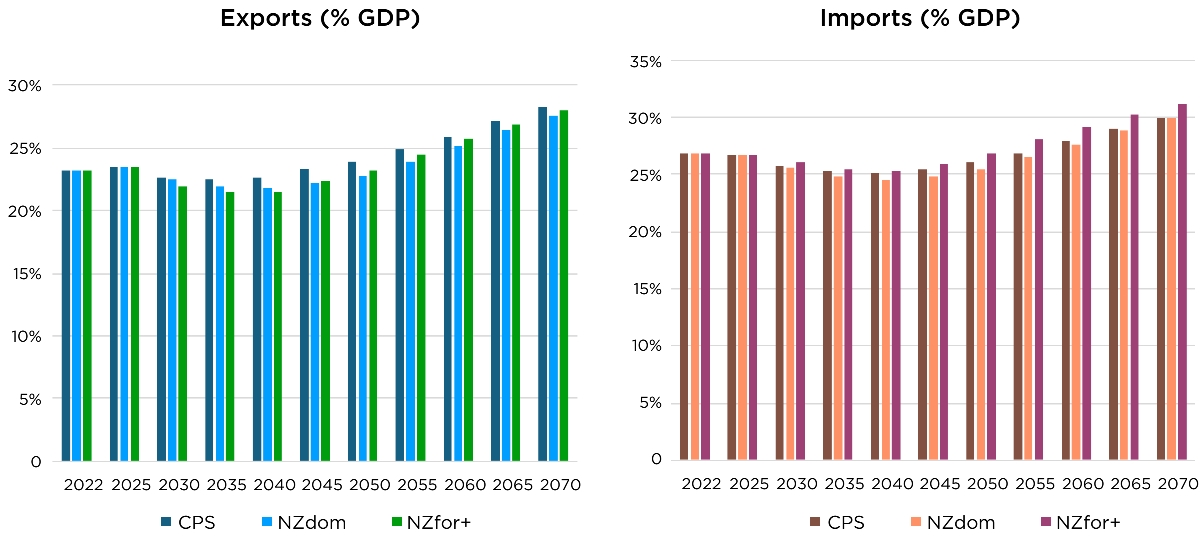
As seen in Figure 7.2 (B), in Net Zero scenarios, exports are projected to be lower by 2% (NZfor+) to 9% (NZdom) relative to Current Policy Scenario, with the variation being maximum between 2040 and 2050, though pressures ease in later years. These scenarios represent extreme scenarios with others falling within this range. In case of imports, during 2040-50, imports are higher by 4% in NZfor+ as compared to being lower by 7% in NZdom relative to Current Policy Scenario.



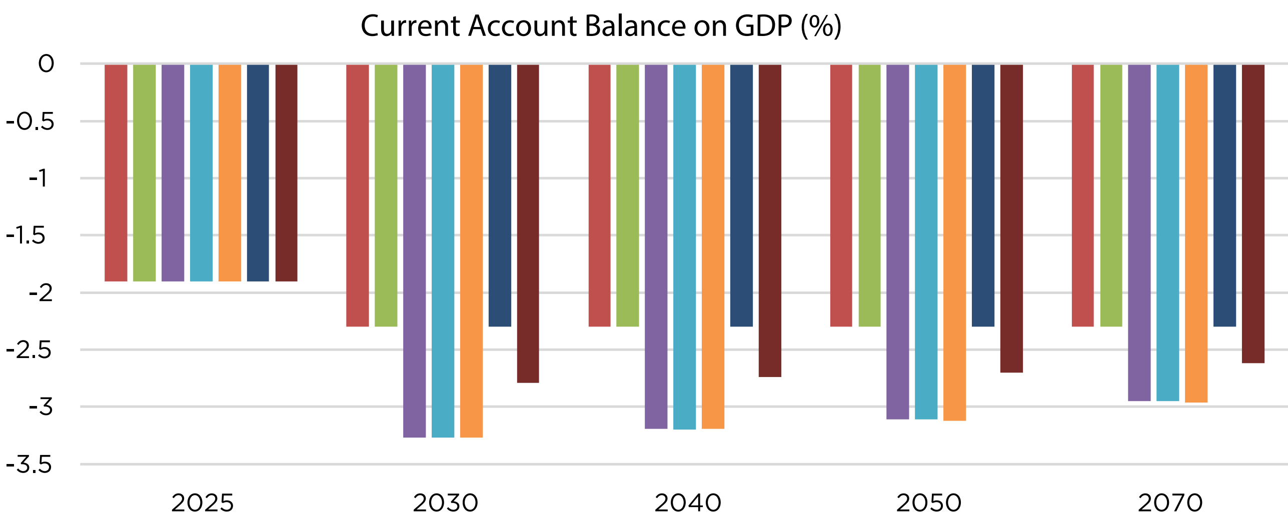
(A)


Consumption
Investment
Exports
Imports
% Deviation from CPS
10%
8%
6%
4%
2%
0%
-2%
-4%
-6%
-8%
-10%
2030 2035 2040 2045 2050 2060 2070
NZdom+
NZdom
NZfor+
NZfor
NZforSub
NZdomSub
NZforRD

(B)


Exports (% GDP)
Imports (% GDP)
35%
30%
25%
20%
15%
10%
5%
0
2022 2025 2030 2035 2040 2045 2050 2055 2060 2065 2070
CPS
NZdom
NZfor+

(C)



(D)

Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 7.2: (A) GDP components (at constant 2012 prices) in the Current Policy Scenario (MANAGE). (B) GDP components (% deviation from CPS) (MANAGE) (C) Exports and imports as a percentage of GDP (MANAGE model) (D) Current account balance (% of GDP, MANAGE model)

The Current Account Deficit is higher in all Net Zero scenarios compared to Current Policy Scenario. Foreign-financed scenarios show larger Current Account Deficit (CAD) (peaking at around 3.2% of GDP in 2045) compared to domestically-financed pathways (stabilizing at 2.3-2.5%) driven by larger foreign inflows. (Figure 7.2 (D))

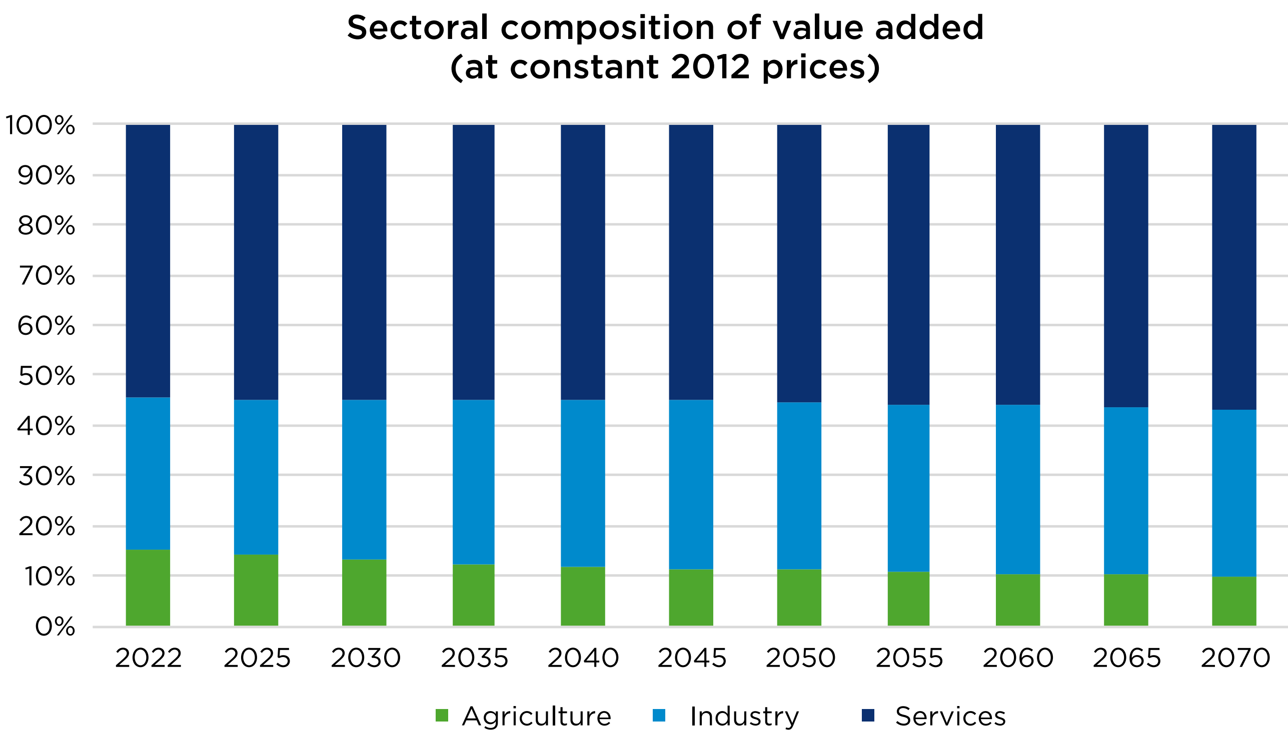
7.2.3 Impact on Sectoral output and shares

India's long-term growth trajectory is characterised by a steady structural shift away from agriculture toward industry and services. Under Current Policy Scenario, agriculture's share in gross value added (GVA) reduces gradually over time (~14.4% in 2025 to 9.8% in 2070), while the share of industry grows from about ~30.7% in 2025 to 33.3% by mid-century and stabilises thereafter. Services remain the dominant sector, with its share growing from 54.9% in 2025 to around 55.5% by mid-century and continuing to increase to 56.8% by 2070 (Figure 7.3 (A)). These changes are mirrored in employment patterns, with labour moving out of agriculture and being absorbed primarily by industry, particularly clean energy manufacturing, construction, and infrastructure-related activities.

In contrast, Net-Zero (NZ) pathways modestly accelerate this transformation without fundamentally altering sectoral balances. The reallocation away from agriculture toward industry and services is preserved across scenarios, with industry benefiting most from Net Zero driven investment in electricity, construction, and clean-energy supply chains.

As seen in Figure 7.3 (B), sectoral outcomes vary by financing structure: domestically financed Net Zero pathways (NZdom) experience temporary lower outputs compared to Current Policy Scenario, especially during 2045–2050, with value added in industry being lower by up to 5–6% and services being lower by around 4–5% relative to Current Policy Scenario. In contrast, foreign-financed and productive investment scenarios (NZfor+) show higher growth, particularly of industry, with value added being higher by 2-2.5% relative to Current Policy Scenario.

Within industry, sharp decline in fossil fuel based activities are offset by expansion in construction and clean energy sectors. Overall, the study shows that Net Zero reinforces India's shift toward higher-productivity, industry-led growth, with financing design playing a decisive role in shaping sectoral outcomes.



(A)

	2030	2035	2040	2045	2050	2060	2070
Agriculture							
NZdom	-0.56	-1.59	-2.76	-3.50	-3.74	-2.62	-2.36
Nzfor+	0.99	1.81	2.11	2.30	2.48	3.03	2.12
Industry							
NZdom	-0.64	-2.52	-4.49	-5.56	-5.64	-2.85	-1.72
Nzfor+	2.06	2.71	2.42	2.32	2.52	4.09	3.69
Services							
NZdom	-0.92	-2.42	-3.87	-4.76	-4.93	-3.27	-2.82
Nzfor+	1.12	1.69	1.64	1.62	1.71	2.16	1.09

(B)

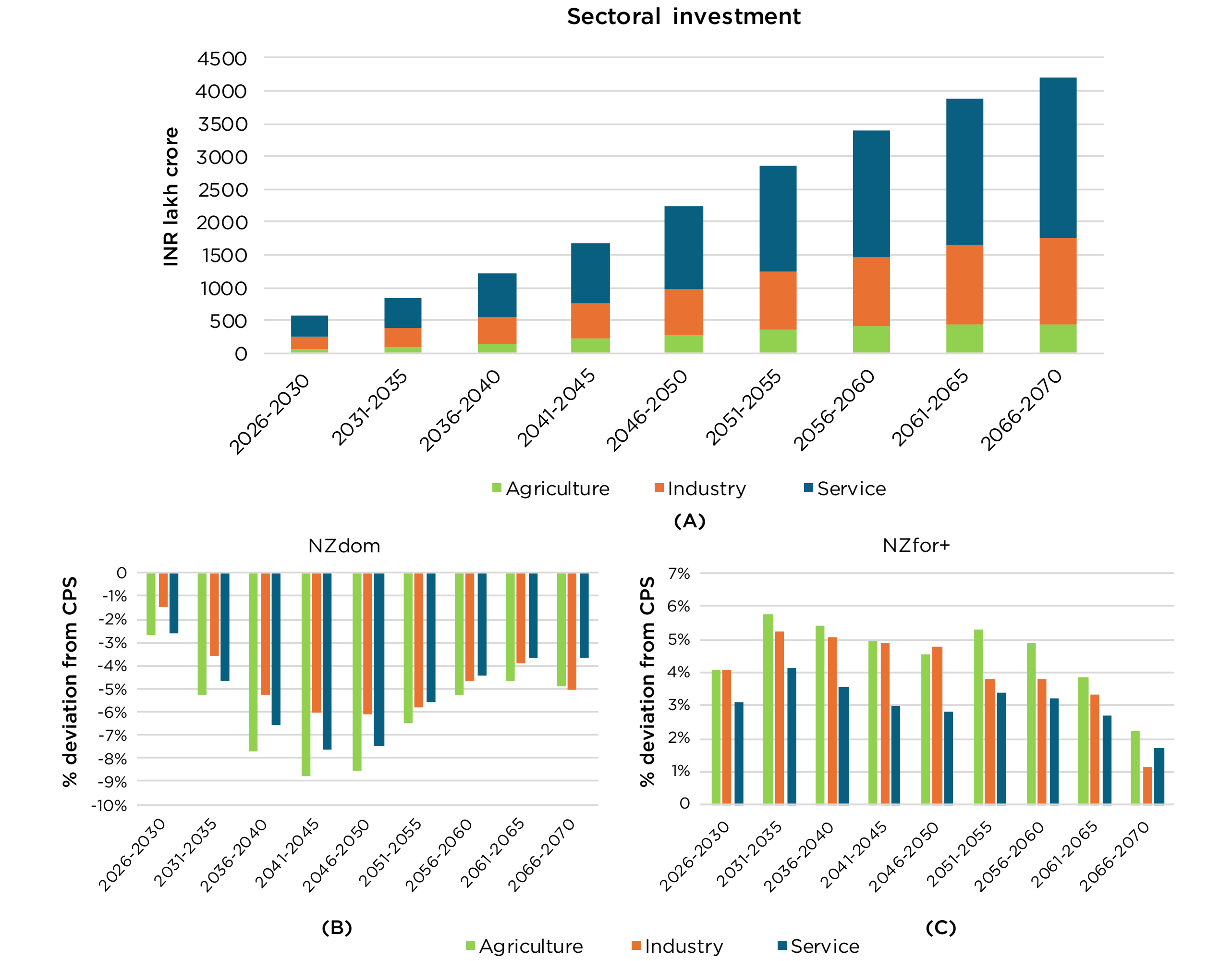
Figure 7.3: (A) GVA sectoral composition in Current Policy Scenario (CPS) (constant 2012 prices, MANAGE model) (B) Sectoral value added (% deviation from CPS, MANAGE model)[xvii]

xvii Colours represent the direction and magnitude of deviation relative to the Current Policy Scenario (CPS). Greener shades indicate positive deviations, yellow denotes values close to CPS, and orange to red shades indicate negative deviations, with darker colours reflecting larger absolute changes.

7.2.4 Impact on Investment

India's growth trajectory is capital-intensive across all scenarios, with total investment quintupling by 2070 (over 2030-35 levels) under Current Policy Scenario (~INR 4,200 lakh cr over 2065-70), highlighting the scale of finance that must be mobilised (Fig 7.4 (A)). The service sector accounts for the largest share of this expansion, followed by industry and agriculture, underscoring the growing importance of services and capital-intensive activities in sustaining long-term growth. This upward trajectory reflects the combined effects of sustained growth, capital replacement, infrastructure expansion, and the economy's gradual shift toward low-carbon sectors.

The deviation of Net-Zero pathways from Current Policy Scenario depends on the source of financing. Domestically financed scenarios (NZdom) lead to crowding-out and slightly lower investment across sectors, though industry is least affected, underscoring its central role in electrification and technology deployment (Fig 7.4 (B)). In contrast, foreign-financed pathways (NZfor+) generate crowding-in effects, with industry attracting larger capital inflows compared to Current Policy Scenario and agriculture benefiting from biomass-related activities (Fig 7.4 (C)). Overall, the transition is highly capital intensive and increasingly driven by clean, hard-to-abate technologies and system-level infrastructure.



Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

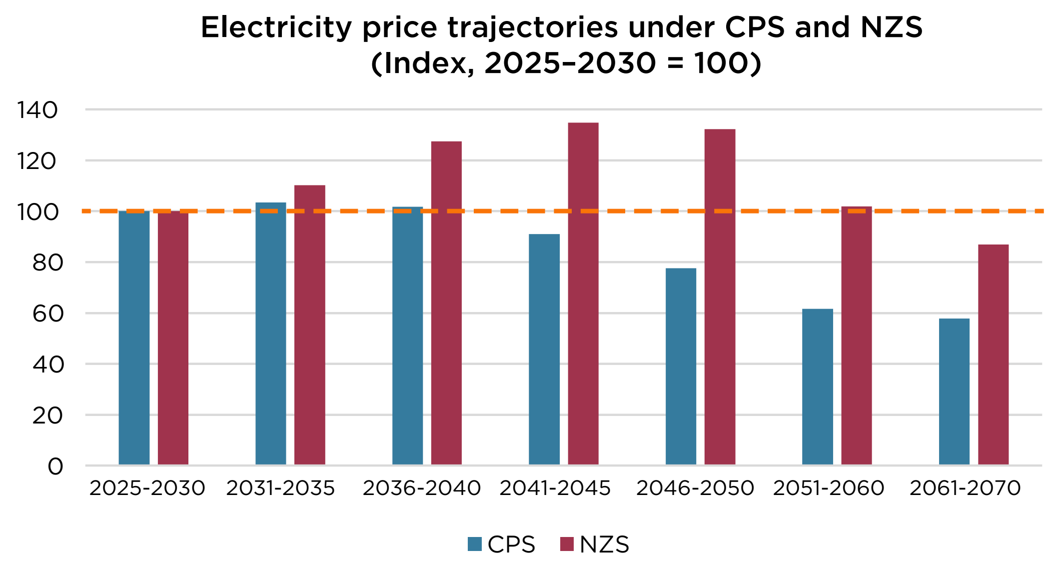
Figure 7.4: (A) Sectoral investment in Current Policy Scenario (B, C) Net Zero Scenario investment (%deviation from CPS) (MANAGE)

7.2.5 Impact on Electricity Price Trajectory

The Current Policy Scenario and Net Zero Scenario show distinct electricity price trajectories (Figure 7.5). In the Current Policy Scenario, slower pace of demand electrification and resulting lower investment needs, leads to electricity prices largely remaining stable till 2040 and declining thereafter.

By contrast, the Net Zero pathway projects higher electricity prices in the near to medium term, particularly over 2030–2045, as rapid electrification of transport and industry drives up electricity demand. Meeting this surge requires substantial upfront capital investment in renewable generation, storage, transmission upgrades, and emerging demand-side electrification options such as heat pumps and electric boilers, which can be more capital intensive than conventional technologies. These higher upfront costs push Net Zero electricity prices above Current Policy levels during the initial phase of the transition.

After 2045, however, Net Zero electricity prices are projected to reduce from their peaks but continue to remain above Current Policy levelsdue to higher electrification in Net Zero. This decline reflects economies of scale, technology learning effects, and continuing cost reductions in low-carbon technologies. By the 2050s and beyond, electricity becomes more affordable under Net Zero, supporting long-term competitiveness, consumer welfare, and sustained economic growth.

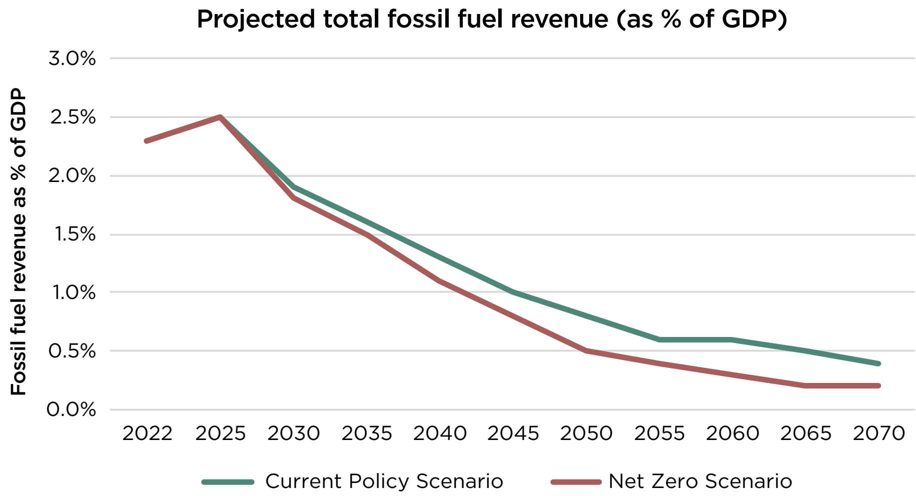


Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

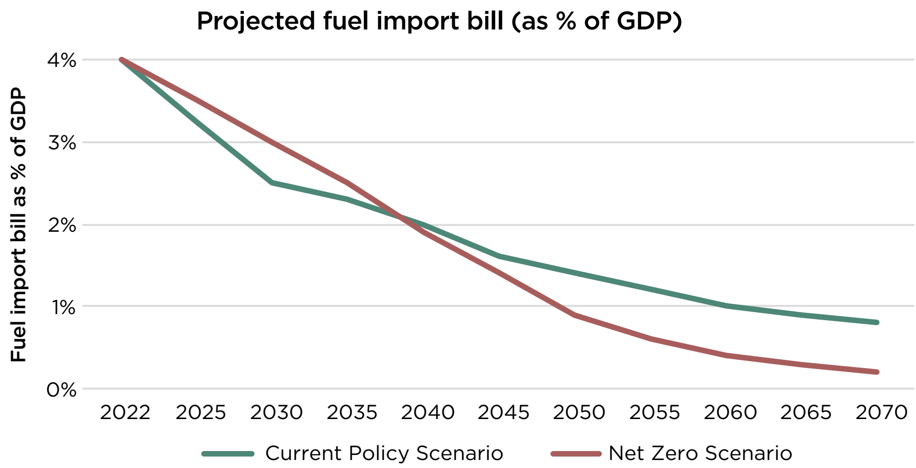
Figure 7.5: Electricity price trajectories under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

7.2.6 Impact on Government Revenue and Import Bill

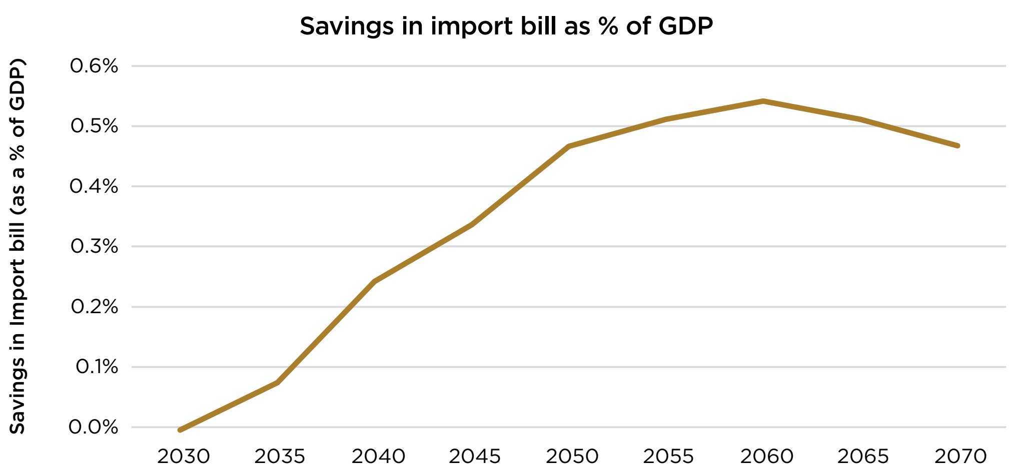
This section explores the impact on government revenue and imports. In Current Policy Scenario, revenues from fossil-fuels are expected to decline from 2.3% of GDP in 2022 to 0.8% by 2050 and 0.4% of GDP by 2070. In the Net Zero Scenario, the revenues are projected to decline to 0.5% of GDP by 2050 and 0.2% of GDP by 2070 (Figure 7.6 (A)). This shift away from fossil fuels also delivers gains through lower import dependence. This is on account of reductions in oil and gas imports, followed by coal. In Current Policy Scenario, the total fuel import is projected to reduce from around 4% of GDP in 2022 to 1.4% by 2050 and 0.8% of GDP by 2070. In Net Zero scenario, it reduces to 0.9% of GDP by 2050 and 0.2% of GDP by 2070. (Figure 7.6 (B)).



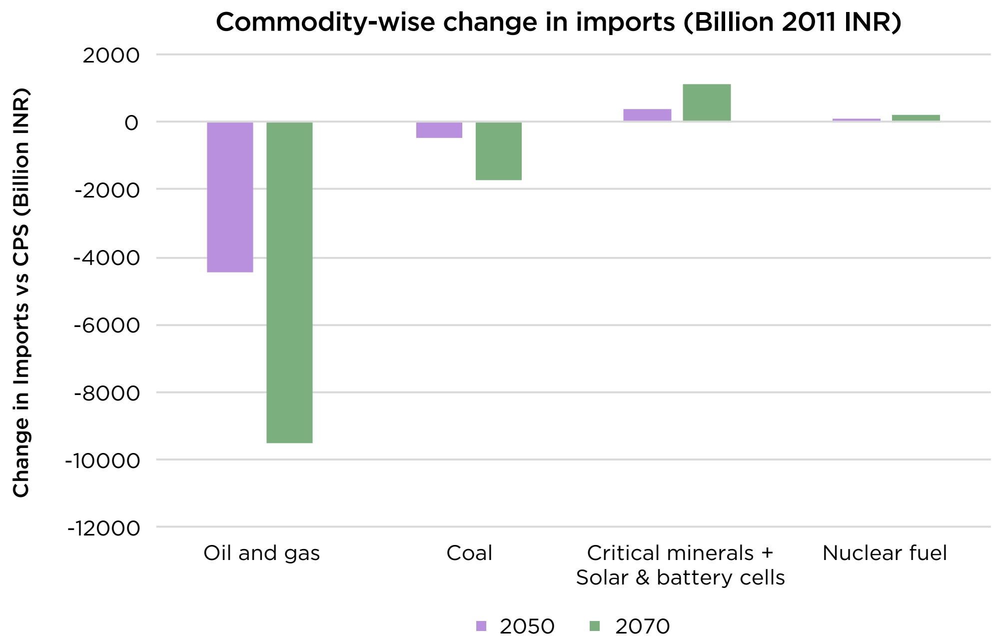
(A)



(B)



(C)



(D)

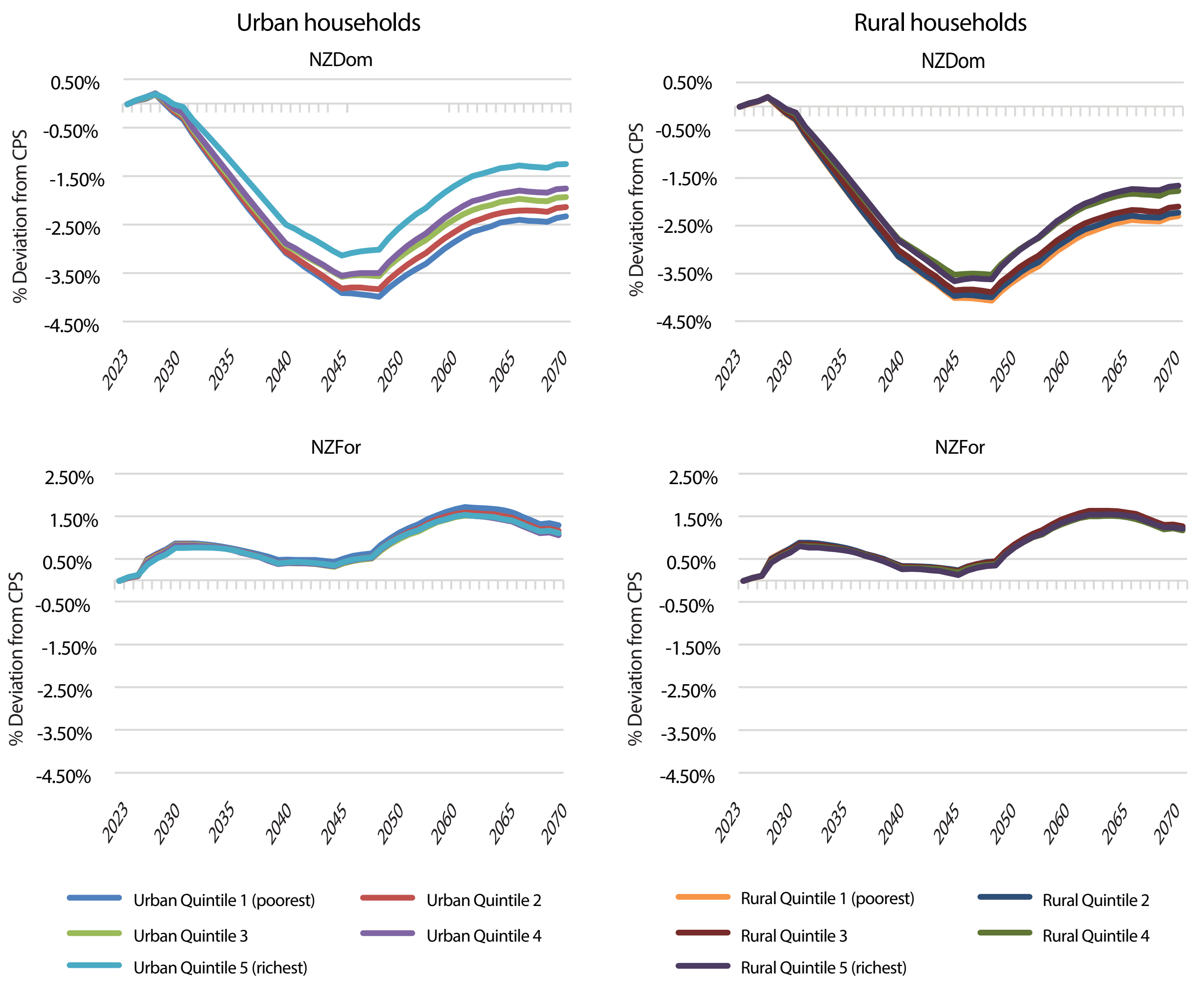
Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 7.6: (A) Projected total fossil fuel revenue (as % of GDP) (B) Projected fuel import bill (as % of GDP) (C) Savings in import bill in Net Zero Scenario compared to Current Policy Scenario as a % of GDP (D) Commodity-wise change in imports in Net Zero Scenario compared to Current Policy Scenario (CPS) in years 2050 and 2070 (Billion 2011 INR)

The imports of critical minerals, solar modules, battery cells, and nuclear fuel are projected to increase under both scenarios. However, these additions are much lower than the expected savings in fossil-fuel imports. As a result, the overall energy fuel import bill is projected to see net savings as early as 2035, at about 0.07% of GDP, rising to about 0.5% of GDP by 2050-70. This highlights that, despite new dependencies on critical minerals, the Net-Zero transition materially strengthens India's external balance over the long term.

7.2.7 Impact on Household Income and Consumption

Under the Net Zero pathways, domestic financing scenarios (NZdom) are projected to reduce household incomes relative to the Current Policy Scenario. In contrast, foreign financing eases these pressures: external capital inflows prevent crowding out of investment, sustain labour demand and incomes, and moderate consumption reductions (Figure 7.7).



Note: CPS = Current Policy Scenario; NZS = Net Zero Scenario

Figure 7.7: Impact of the Net Zero transition on real household consumption (% deviation from CPS, MANAGE model)

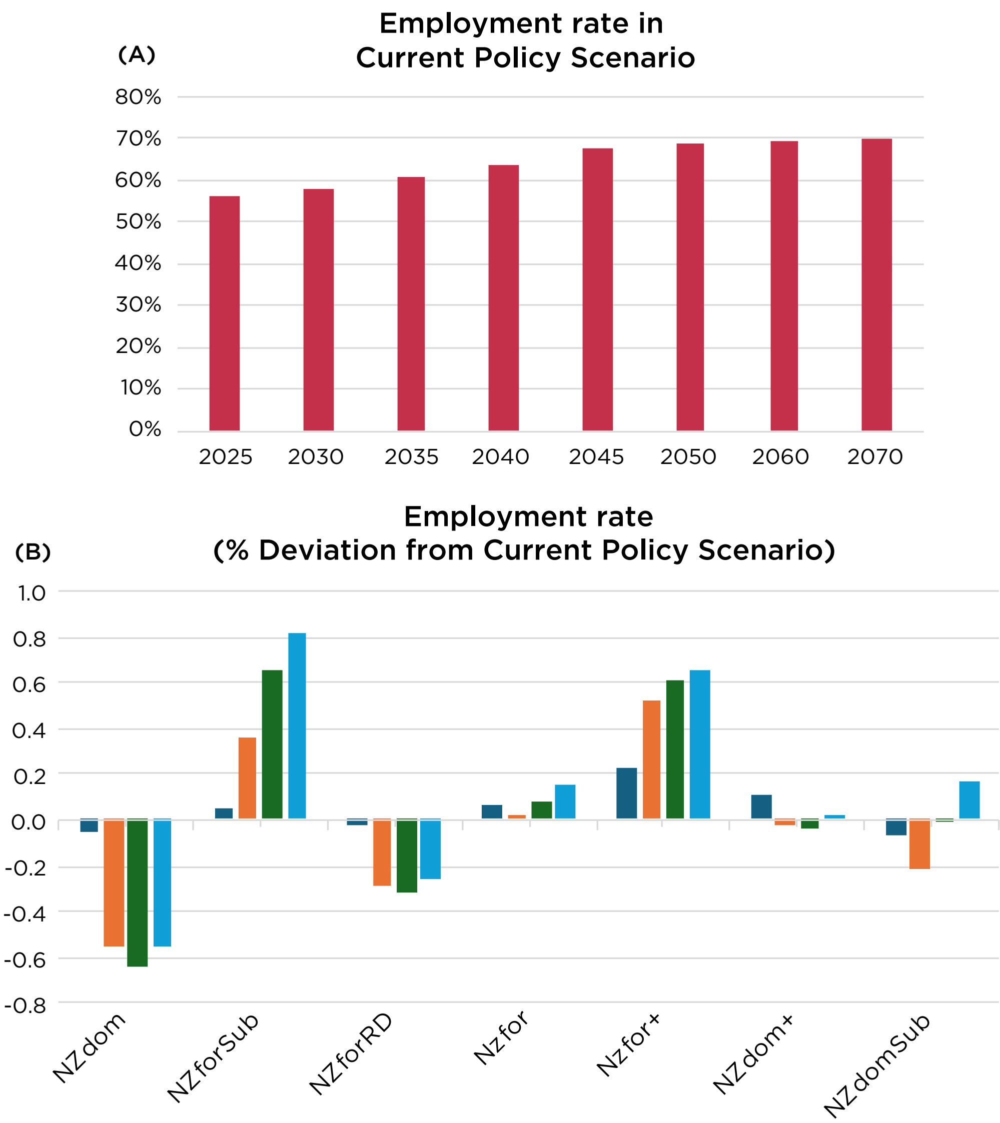
Redistributive policies can offset these adverse effects. Targeted transfers through revenue distribution (NZForRD) maintain the consumption of the bottom 40 percent at Current policy Scenario levels. This shows that redistribution can mitigate short-term distributional impacts of Net Zero. Similarly, electricity subsidies (NZForSub) funded by phasing out fossil fuel subsidies reduce household electricity costs, cushioning welfare losses.

7.2.8 Impact on the Labour Market

As India becomes a USD30 trillion economy by 2047, labour force participation is projected to increase commensurately with the Labour Force Participation Rate (LFPR) improving from 55% in 2025 to 64% in 2050 and 70% in 2070. (Figure 7.9 (A)). Net Zero impacts on the overall employment rate are seen to be relatively modest (+/- 1%). Scenarios such as NZforSub and NZfor+ result in a higher employment rate compared to Current Policy Scenario. Conversely, the NZDom and NZforRD scenarios show a marginally lower employment rate compared to Current Policy Scenario (Figure 7.8 (B))

Employment structure: In both the Current Policy and Net Zero scenarios, employment is projected to shift steadily from agriculture toward industry and services, mirroring the structural transformation of the economy. In Current Policy Scenario, agricultural share of total jobs is projected to go from about 46% in 2025 to 34% by 2050 and 26% by 2070. The reducing share of agriculture in employment is offset by growth in industry especially clean energy manufacturing sectors with industry share projected to go from 24% in 2025 to 34% by 2050 and 39% by 2070.

In terms of Net Zero scenarios, the impact on this structure is marginal. Compared to Current Policy Scenario, in domestically financed Net Zero scenarios, employment in the services sector is lower by 1-2% in 2050 and 0-0.5% in 2070 due to higher electricity prices and crowding-out of capital. However, in foreign financing scenarios, this is moderated as the impact of crowding-out is limited. A similar trend is also observed in the industrial sector.



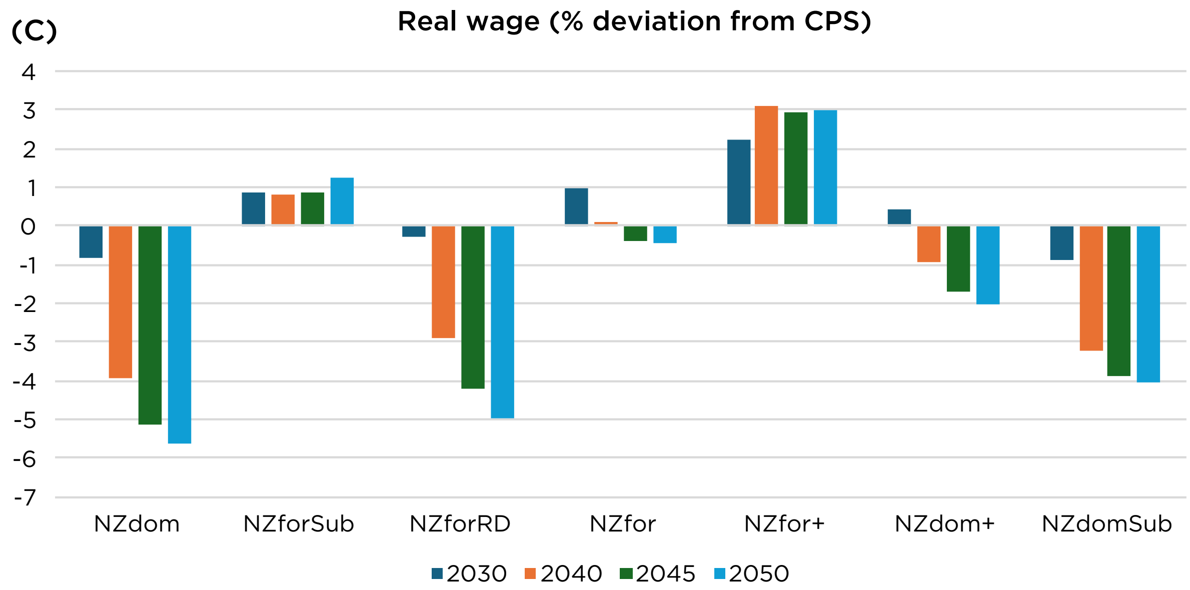


Figure 7.8: (A) Current Policy Scenario employment rate (MANAGE model) (B) Net Zero Scenario employment rate (% deviation from CPS (MANAGE model)) (C) Real wages in Net Zero Scenario (% deviation from CPS) (MANAGE model).

In the Current Policy Scenario, with significant fossil fuel share being there in 2050, direct and indirect employment in the energy sector largely remain stable at around 6 million in 2022 but is projected to be 4.2 million by 2070 as fossil fuel share reduces due to commercial maturity of emerging technologies post-2050. In the Net Zero scenario, driven by greater demand for clean technologies, the total direct and indirect employment in the energy sector is projected to increase from 6 million in 2022 to 7 million by 2050 in domestically financed scenarios compared to 6.7 million in foreign financed scenarios due to higher wage growth.

Wage impact: Real wage deviations from the Current Policy Scenario remain small in the near term but widen after 2040. In the most optimistic foreign-financed scenario (NZfor+), real wages are higher compared to Current Policy Scenario by up to 3% by 2050. Wages are lower by about 5.1% compared to Current Policy Scenario under domestically financed scenarios (NZdom) by mid-century (see Figure 7.8 (C)).

7.3 CHALLENGES AND SUGGESTIONS

The macroeconomic assessment indicates that the Net-Zero pathway can remain broadly consistent with India's long-term growth ambition of becoming Viksit Bharat, a developed nation by 2047. It also highlights a distinct set of transition issues: large, front-loaded investment needs, sensitivity of investment and consumption outcomes to the financing mix, and exposure to evolving carbon-linked trade measures and compliance requirements.

Distributional and labour-market impacts are marginal at an economy-wide level and are more relevant in terms of composition and transition risks. While aggregate employment remains broadly stable across scenarios, outcomes vary by financing structure and policy design: domestically financed pathways are associated with higher capital costs and lower labour demand, whereas foreign-financed pathways enable stronger employment outcomes. These differences imply that the central labour challenge of the transition is not the quantity of jobs but the reallocation of jobs across sectors, regions, and skill levels, particularly as activity contracts in fossil-fuel linked value chains and expands in clean manufacturing, construction, and infrastructure. Absent anticipatory adjustment mechanisms, this reallocation can generate localized dislocation and wage dispersion even as national employment indicators remain stable.

Against this backdrop, the macro transition raises four interlinked policy issues where targeted measures can help ease transition issues while preserving growth and development objectives.

1. Geopolitics: Adapt to fragmentation and anchor low-carbon competitiveness

India's transition is unfolding in a more fragmented and protectionist global economy. "Slowbalisation," friend-shoring, and trade diversion are reshaping supply chains just as climate-related non-tariff measures rise in CO_2-intensive sectors. Analysis of the recent trade-volume patterns suggests that China's export volumes continue to grow since 2020, while world exports excluding China have remained stagnant. This implies that any meaningful derisking from China would likely require stronger trade measures such as tariffs, local-content requirements, subsidies, and tighter screening which can raise input costs and reduce efficiency, shifting resilience into a higher-cost equilibrium.

This challenge is compounded by the fact that the development context that enabled East Asia's rapid catch-up and industrial development in the 20^{th} century was materially different. The geopolitical backdrop then was more supportive of export led growth, there was no energy-transition constraint, demographics were more favourable, and industrial policy was tightly focused on productivity and performance backed by sustained investment in primary education and vocational training.

In contrast, India is attempting to develop under constraints that China and the rest of East Asia did not face: a global model of capital-intensive growth that sits at odds with India's labour endowment, an energy-transition "double-whammy" for capital-led manufacturing ambitions, and rising AI/robotics pressures that threaten services jobs first and physical labour later, together posing risks to social stability if jobs and productivity do not keep pace.

If fragmentation intensifies, the IMF estimates potential GDP losses of 1.5–3.3%. The EU's CBAM and EUDR together could affect ~USD 9.5 billion of Indian exports to the EU (about 12.9% of India's exports to bloc), turning sustainability standards into both barriers and competitive filters.

Tariff flare-ups, supply-security priorities, and constraints in critical minerals and clean-tech inputs could reduce market access and raise cost and volatility. India must balance "just-in-time" efficiency with "just-in-case" resilience while moving up the value chain in low-carbon exports.

Suggestions:

i. **Strategic trade diplomacy and trade-linked investment:** Proactively pursue FTAs with major partners that combine large import demand and significant outward investment. The FTAs with EU, United States, Japan, United Kingdom, and the Republic of Korea, should enable a greater focus extending beyond tariff liberalisation to cooperation on certification systems, carbon measurement protocols, digital trade rules, and closer regulatory alignment.

ii. **Strengthen domestic supply-chain resilience:** Identify critical dependencies (lithium, solar PV components, semiconductors, rare earths) and diversify import sources via long-term offtakes and equity stakes (Africa, Latin America), alongside domestic manufacturing and exploration. Maintain strategic stockpiles for vulnerable inputs; collaborate through country groups (e.g., QUAD, ISA) for coordinated responses.

iii. **Focus on specialisation and comparative advantage:** Use the National Manufacturing Mission to deepen "networked specialisation" in electronics/semiconductors, apparel and textiles, automobiles and components, and toys/capital goods/light manufacturing, embedding low-carbon production as a comparative advantage (e.g., green steel, green ammonia, sustainable textiles). Support exports with a stable policy and lower import duties on essential intermediate inputs/equipment for these green value chains.

iv. **Diversify exports and build monitoring systems for global standards.** Invest in certification and monitoring infrastructure (including traceability for European Union Deforestation Regulation covered goods) so exporters can meet emerging global requirements at scale.

v. **Accelerate industrial low-carbon growth to pre-empt barriers.** Fast-track greening of trade related sectors (steel, cement, chemicals, engineering goods). Establish plant-level Measurement, Reporting, and Verification (MRV) for emissions and product carbon content to demonstrate compliance with regimes like CBAM; participate in sectoral alliances (e.g., low-carbon steel, green shipping fuels).

2. Scaling Infrastructure to enable low-carbon transition

A defining macroeconomic feature of India's Net-Zero pathway is the scale and front-loaded nature of infrastructure investment, particularly in power generation, transmission and distribution networks, storage, industrial electrification, transport systems, and urban infrastructure. The modelling results indicate that electricity prices are projected to be higher in the near to medium term under Net-Zero pathways due to the capital intensity of rapid electrification and system expansion, before coming down in later decades as technology costs decline and scale economies materialise.

This investment profile underscores that infrastructure constraints are not merely sectoral bottlenecks but macro-critical determinants of growth, competitiveness, and fiscal sustainability. Delays or underinvestment in grids, storage, logistics, and industrial infrastructure risk amplifying transition costs by raising energy prices, constraining private investment, and reinforcing the crowding-out effects observed in domestically financed scenarios.

Suggestions:

i. **Advance higher upfront investment in Net Zero enabling infrastructure**, supported by greater mobilisation of long-horizon foreign capital, including sovereign wealth funds and global pension funds. When externally financed, this front-loading avoids crowding out domestic investment while delivering productivity gains and lower long-term energy and import costs.

ii. T**argeted public investment in network infrastructure** particularly electricity transmission and distribution and EV charging, can reduce coordination failures and project risk, thereby unlocking larger flows of private capital into renewable energy, e-mobility, and related low-carbon sectors.

iii. **Focus investment on macro-critical areas** such as power grids and storage, urban transport, charging networks, multimodal logistics, water systems, energy efficiency, and waste management to simultaneously support low-carbon transition, service delivery, and long-term economic competitiveness.

3. Harnessing the Green Jobs and Structural Transformation Opportunity

The macro results suggest that India's Net-Zero transition reinforces rather than disrupts India's long-term structural transformation, with employment shifting steadily from agriculture towards industry and services, and with clean energy manufacturing, construction, and infrastructure emerging as important employment drivers. However, these aggregate trends mask significant adjustment issues at the sectoral, regional, and skill levels.

In particular, the expansion of clean energy, electrification, and low-carbon manufacturing and the contraction of fossil-fuel linked value chains create a transitional labour market that needs matching of skills and emerging job profiles, as well as spatial mismatches between regions.

Suggestions:

i. **Scale skilling efforts toward green and digital sectors**, anchored in strong foundational capabilities and aligned with market demand. A Green and Digital Skills Stack covering NSQF-aligned green roles, micro-credentials enabling laddered progression, and industry-co-designed curricula can support adaptive, technology-ready labour.

With over a quarter of Indian workers in AI-exposed occupations, workforce strategies can increasingly **integrate reskilling for AI-complementary** roles while mitigating displacement risks, particularly as structural transformation accelerates beyond agriculture.

ii. **Formal recognition of green gig roles** such as EV drivers, solar technicians, and e-waste handlers alongside expanded social protection and benefit portability can strengthen labour inclusion as green sectors scale.

iii. **Uniform implementation of labour codes** across states can improve hiring flexibility, encourage formalisation, and enhance India's attractiveness for labour-intensive and clean manufacturing, while remaining responsive to evolving technological and market uncertainties.

4. Regulatory and Institutional Reform for a Capital-Intensive Transition

The macroeconomic outcomes of the Net-Zero transition are shown to be highly sensitive not only to the volume of investment mobilised but also to its productivity, financing structure, and institutional environment. Productive investment scenarios deliver superior GDP, wage, and employment outcomes relative to other pathways, underscoring the importance of institutional quality and regulatory design in shaping transition outcomes.

Regulatory and institutional issues arise across multiple dimensions: land acquisition and permission delays affecting infrastructure rollout; multiplicity of governance structures across sectors and levels of government; evolving regulatory frameworks for emerging technologies such as hydrogen, CCUS, and small modular reactors; and the fiscal implications of declining fossil fuel revenues combined with rising transition-related expenditures.

Suggestions:

i. **Improve enforcement of energy codes and modernise municipal bylaws** by linking budgetary allocations to verified Energy Conservation Building Code (ECSBC) and Eco Niwas Samhita (ENS) compliance rates and streamlining digital building approvals, thereby making energy-efficient construction the default. Greater harmonisation of state building codes with national frameworks can further optimise land use and reduce energy demand in urban development.

ii. **Build investor confidence through stable, transparent, and predictable regulatory regimes**, lowering the cost of capital for climate-aligned infrastructure and improving bankability for long-horizon domestic and foreign investors. Forward visibility on performance standards for key sectors can further strengthen investment planning in low-carbon technologies.

iii. **Rationalise fossil fuel subsidies** over the medium term while ensuring targeted support for vulnerable groups, thereby reducing fiscal distortions without compromising equity or energy access.

iv. **Widen fiscal capacity** through selective tax reforms, and simplifying compliance, enabling greater public investment in low-carbon infrastructure and human capital without undermining growth.

8

CRITICAL MINERALS AND SUPPLY CHAINS

Critical Minerals and Supply Chains

8

Low-Carbon Technologies (LCTs), such as solar photovoltaic (PV), Battery Energy Storage System (BESS), wind turbines, electrolyser, and Zero Emission Vehicles (ZEVs), will need to scale rapidly for India to achieve Net Zero Emissions by 2070. Several of these technologies depend on critical minerals such as lithium, nickel, cobalt and rare-earth elements. At present, the global supply is concentrated in a few countries, exposing India to risks of price volatility and supply disruption (International Energy Agency, 2024).

To strengthen supply security, India has undertaken wide-ranging policy reforms across the value chain. Amendments to the Mines and Minerals (Development and Regulation) (MMDR) Act introduced competitive auctions, established the District Mineral Foundation (DMF) and National Mineral Exploration Trust (NMET). The regulatory framework was expanded to include critical and strategic minerals as well as offshore resources. In 2023, the Ministry of Mines released a list of 30 critical minerals spanning electronics, defence, and renewable energy, later classifying 24 as 'Critical and Strategic Minerals' under the MMDR Act. These steps have improved transparency and institutional architecture. However, challenges remain in converting auctioned blocks into operational mines and scaling private participation in exploration.

Complementing domestic reforms, India has pursued international strategies through overseas acquisitions by Khanij Bidesh India Limited (KABIL), duty exemptions, and partnerships such as QUAD, the Minerals Security Partnership, and bilateral collaborations with Australia and the United States. The approval of the National Critical Minerals Mission in 2025 integrates domestic exploration, overseas sourcing, recycling, and value-chain development under a unified framework, reinforcing India's strategic approach to securing minerals essential for its clean energy transition.

Chapters 4 and 5 discussed both the scale and time-horizon of low-carbon technologies such as renewables, green hydrogen, and demand electrification. Building on that, the focus of the Critical Minerals Working Group was to estimate the underlying mineral and material demand required to deploy these technologies. This study assesses India's Critical Energy Transition Minerals (CETMs) requirements under both the Current Policy Scenario (CPS) and the Net-Zero Scenario (NZS), and examines how this demand can be met through domestic resources, recycling, and international sourcing. Demand projections are derived from the anticipated deployment of solar PV, concentrated solar, wind turbines, electric vehicles, battery energy storage systems, and hydrogen electrolysers, with cumulative requirements estimated through 2070. The detailed methodology and assumptions underpinning this analysis are available in the Working Group report on Critical Minerals (Volume 10).

8.1 CUMULATIVE DOMESTIC DEMAND FOR CRITICAL ENERGY TRANSITION MINERALS (CETMs)

Projections indicate a cumulative CETM demand of ~169 million tonnes (Mt) under the Net Zero Scenario (NZS), about 51% higher than Current Policy Scenario (CPS) (~112). As seen in Figure 8.1 and Table 8.1, Copper and graphite emerge as the CETMs with the highest cumulative demand by 2070, at roughly 66 Mt and 46.4 Mt, respectively under NZS. Copper's dominance reflects its widespread application across solar PV, wind turbines, EV batteries, EV motors, and electrolysers. Graphite demand arises almost entirely from battery anodes, with more than 95% demand from EV batteries and BESS.

Silicon demand is expected to be ~19 Mt, driven mainly by solar PV deployment. Phosphorus demand reaches ~16.6 Mt, reflecting its critical role in Lithium Iron Phosphate (LFP) batteries in both EVs and BESS. Nickel demand is also expected to be significant at ~11 Mt due to its applications in EV batteries, BESS, wind turbines and electrolysers. Other high-volume CETMs include lithium at ~5.4 Mt, cobalt at ~1.4 Mt, and vanadium at ~0.7 Mt, all linked to battery technologies.

India's projected CETM requirements reveal distinct functional clusters with clear concentration patterns across technologies. Bulk-use base metals such as copper and nickel underpin EV batteries, motors, solar systems, and storage.

Energy storage critical minerals including graphite, lithium, phosphorous, cobalt, and vanadium dominate battery chemistries. EV batteries alone are expected to account for ~55% of total CETM demand by 2070. Battery energy storage systems are expected to add another ~5%, reflecting concentrated reliance on graphite, nickel, cobalt, vanadium, and copper.

Solar technologies are expected to contribute ~31% of cumulative demand, driven by copper and silicon alongside smaller volumes of tin, indium, tellurium, and selenium. These niche minerals are essential for advanced PV technologies and expose vulnerabilities in supply chains due to their geopolitical sensitivity.

Wind energy is projected to contribute ~6% of the cumulative demand, primarily through rare earth elements and copper. Rare earths such as neodymium, praseodymium, dysprosium, terbium, and yttrium, are indispensable for permanent magnets in EV motors and wind turbines. EV motors themselves account for ~3% of overall demand, concentrated in Rare Earth Elements (REEs) alongside copper.

Electrolyser-specific minerals such as iridium, platinum, zirconium, and lanthanum, though low in volume (~0.7% of demand), are vital for green hydrogen production and geopolitically sensitive due to supply concentration.

Finally, a long-tail of minerals including molybdenum, titanium, tin, germanium, and gadolinium, though smaller in aggregate demand, remain strategically important for specialised applications and future innovations. These warrant sustained policy attention despite their relatively low overall volumes.

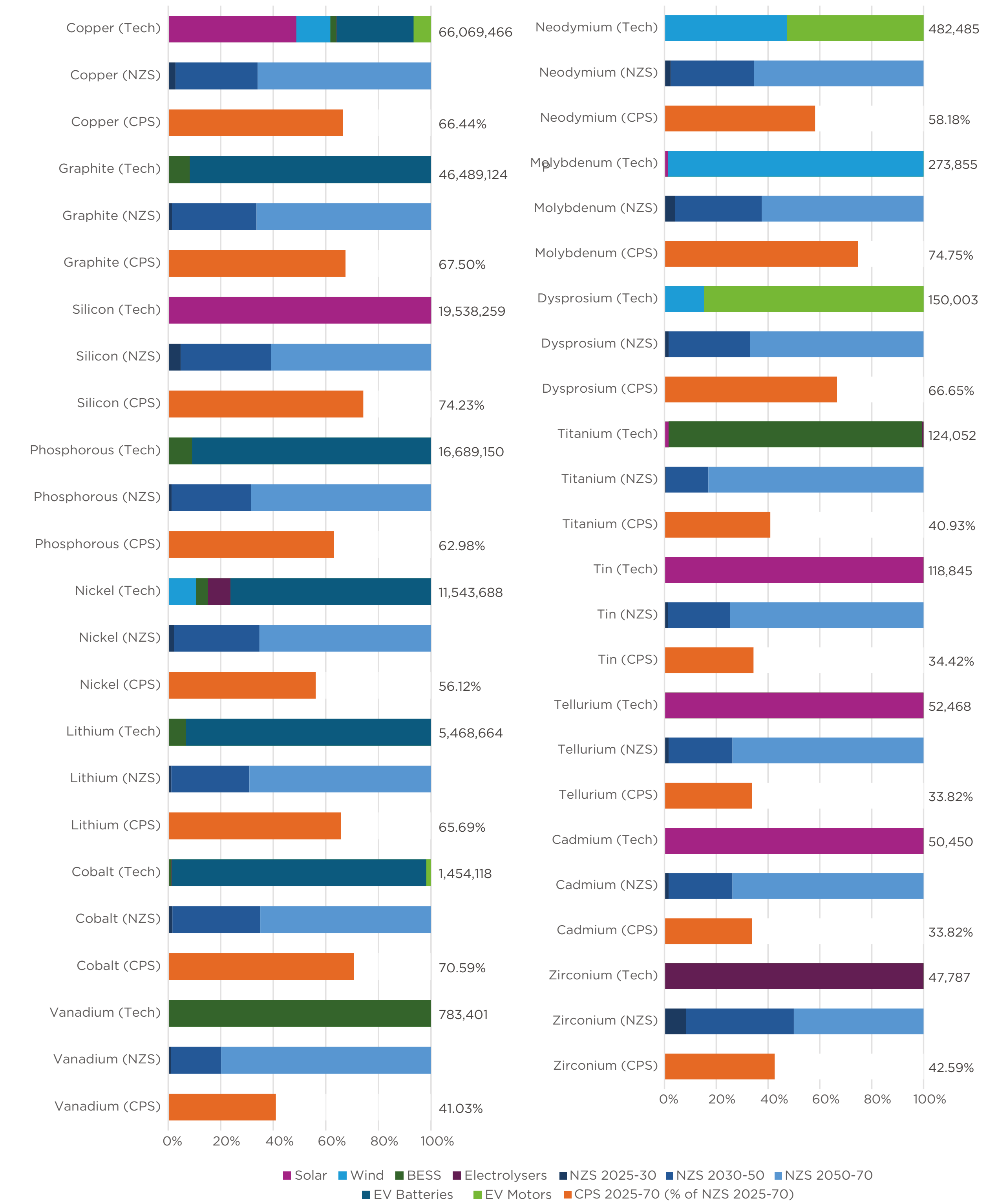


Figure 8.1a: Cumulative mineral demand in Current Policy Scenario (CPS) & Net Zero Scenario (NZS)

(Interpretation of graph - Bar 1: Share across different technologies under NZS; Bar 2: Share across different time horizons under NZS; Bar 3: Proportion in CPS relative to the NZS; Secondary y-axis: – Total demand under the NZS (Tonnes) and percentage in CPS relative to NZS)

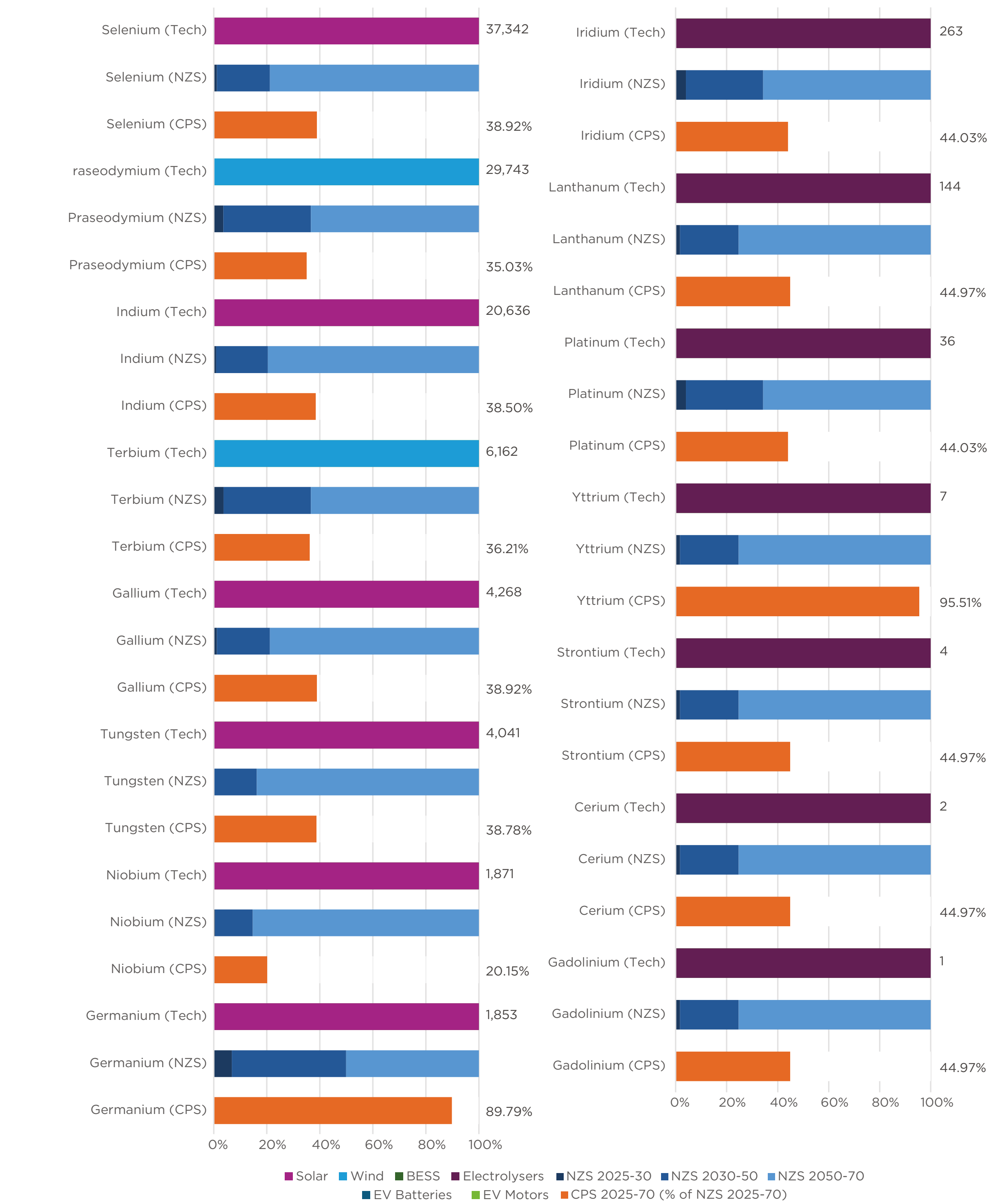


Figure 8.1b: Cumulative mineral demand in Current Policy Scenario (CPS) & Net Zero Scenario (NZS)

(Interpretation of graph - Bar 1: Share across different technologies under NZS; Bar 2: Share across different time horizons under NZS; Bar 3: Proportion in CPS relative to the NZS; Secondary y-axis: – Total demand under the NZS (Tonnes) and percentage in CPS relative to NZS)

Table 8.1: Demand for Critical Energy Transition Minerals at different time horizons

Name	Current Policy Scenario (Tonnes)			Net Zero Scenario (Tonnes)		
	2025-2030	2031-2050	2051-2070	2025-2030	2031-2050	2051-2070
Copper	1,447,931	13,917,166	28,532,628	1,882,424	20,623,186	43,563,856
Graphite	279,372	10,237,656	20,862,674	700,016	14,955,111	30,833,997
Silicon	858,502	4,794,167	8,851,178	924,808	6,738,516	11,874,935
Phosphorous	80,274	3,409,639	7,668,264	214,298	5,044,803	11,430,049
Nickel	133,218	2,585,554	5,307,677	253,940	3,758,838	7,530,909
Lithium	27,118	1,119,950	2,601,999	66,305	1,624,768	3,777,590
Cobalt	11,574	336,336	660,669	23,598	478,156	926,934
Vanadium	1,756	65,802	253,890	8,274	149,672	625,455
Neodymium	4,441	90,600	185,657	11,689	154,897	315,898
Molybdemum	7,230	71,045	126,440	11,298	91,786	170,771
Titanium	150	8,985	41,642	635	20,347	103,070
Dysprosium	954	31,410	67,497	2,363	47,152	100,488
Tin	1,330	11,160	28,417	1,706	28,318	88,821
Tellurium	709	5,789	13,476	1,047	14,965	42,618
Cadmium	622	4,850	11,588	788	12,435	37,227
Selenium	260	2,898	11,377	460	7,452	29,430
Zirconium	2,001	6,930	11,420	4,001	19,867	23,919
Praseodymium	330	3,624	6,583	1,092	9,802	18,849
Indium	117	1,648	6,296	208	4,104	16,587
Tungsten	0	315	1,252	0	656	3,385
Gallium	30	331	1,300	53	852	3,363
Niobium	4	56	318	10	265	1,596
Germanium	241	804	618	126	798	928
Lanthanum	1.2	11	52	2	33	108
Platinum	0.7	4	11	1	11	23
Yttrium	0.1	1.2	5.4	0.1	1.6	5.3
Strontium	0.0	0.3	1.5	0.1	1.0	3.2
Cerium	0.0	0.2	0.8	0.0	0.5	1.6
Gadolinium	0.0	0.0	0.2	0.0	0.1	0.4

Global Context: Placing India's projected CETM demand in a global context provides a clearer picture of the country's role in international mineral value chains. This assessment compares the projected CETM demand in 2050 with global demand projections published in the Global Demand Outlook (2025) of the International Energy Agency (IEA). Both datasets focus on mineral requirements for clean energy technologies such as batteries, solar PV, wind turbines, and electric vehicles in a net-zero pathway. These results are presented in Figure 8.2. India's projected CETM demand in 2050 under Net Zero Scenario constitutes an average 9% of global demand.

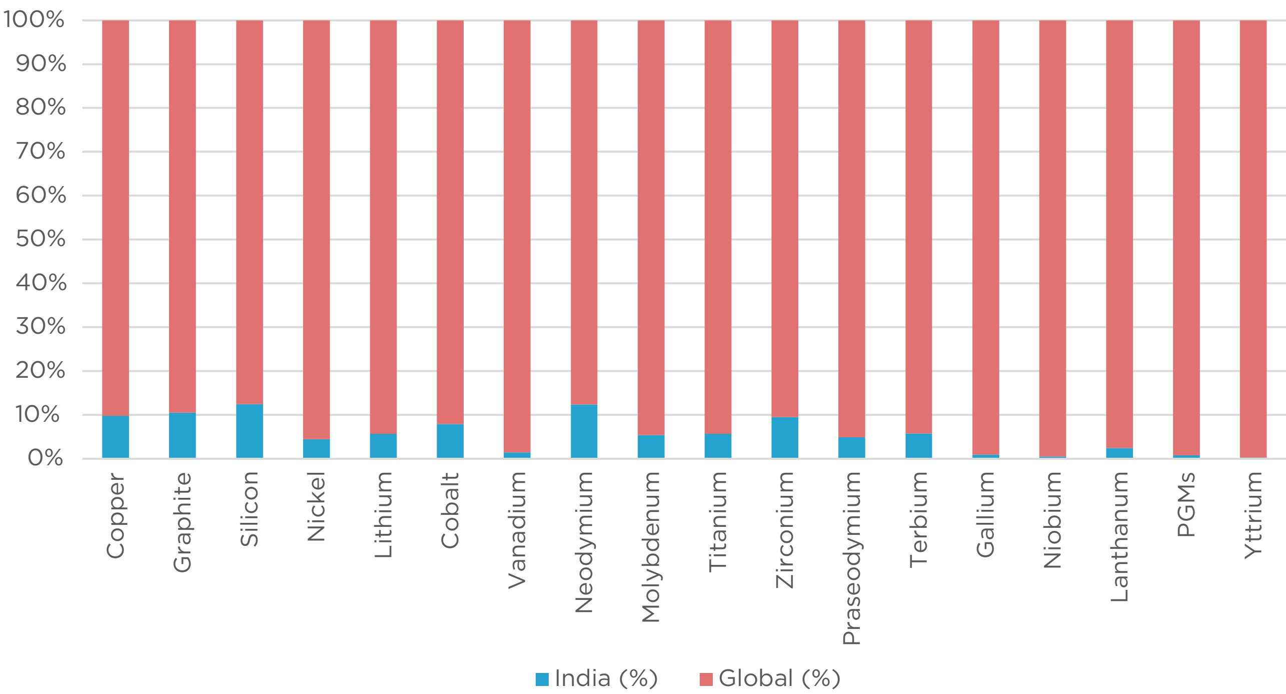


Figure 8.2: India's CETM demand as share of global demand in the Net Zero Scenario

Within this, India's demand clusters into distinct buckets. A mid-tier group of minerals, with shares around 10–15% of global demand, reflects India's strong build-out in solar PV, batteries, and permanent magnets. A second group, with 3–10% of global demand, supports EVs, storage, wind, and electrolysers. Finally, a set of trace demand minerals, each below 3% of global totals, remain low in aggregate but strategically important for specialised applications.

8.2 SUPPLY ASSESSMENT OF CETMs

The supply-side assessment adopts a multi-pronged analytical approach to evaluate India's exposure to CETM supply risks. It examines long-term demand projections (2025–2070) in relation to domestic resource availability, certified reserves, and import dependence, through an assessment of India's readiness across mining, processing, and recycling stages. It further analyses India's trade exposure by mapping key mineral imports against geopolitical, governance, and concentration risks in supplier countries. In addition, the assessment reviews structural vulnerabilities in global critical mineral supply chains, drawing on international evidence from the past decade.

Table 8.2 below compares cumulative embedded mineral demand (2025–2070) with remaining resources, certified reserves, and import reliance for 23 priority CETMs. India's projected CETM demand growth outpaces the availability of domestically certified reserves.

Table 8.2: Comparison of CETM demand with resources, reserves and import dependence[xviii]

	Minerals	Demand 2025-2070* (kt)	Resource[xix] (kt)	Reserves[xx] (kt)	Import Dependence[xxi] (%)
1	Copper	66,069.47	1,496,979.00	163,891.00	57
2	Graphite	46,489.12	203,060.18	8,563.41	28
3	Silicon	19,538.26	-	-	100
4	Phosphorous	16,689.15	280,377.39	30,876.09	85
5	Nickel	11,543.69	1,89,000.00	-	100
6	Lithium	5,468.66	-	-	100
7	Cobalt	1,454.12	45,000.00	-	100
8	Vanadium	783.40	24,633.86	-	46
9	REE	668.55	459.73	-	100
10	Molybdenum	273.86	27,203.40	-	100
11	Titanium	124.05	411,108.53	15,998.63	0
12	Tin	118.84	102.78	0.97	100
13	Tellurium	52.47	-	-	-
14	Cadmium	50.45	5.69	-	-
15	Zirconium	47.79	1,674.44	669.47	78
16	Selenium	37.34	-	-	100
17	Indium	20.64	-	-	100
18	Gallium	4.27	-	-	100
19	Tungsten	4.04	144.65	-	100
20	Niobium	1.87	-	-	100
21	Germanium	1.85	-	-	100
22	PGE	0.30	0.02	-	100
23	Strontium	0.004	-	-	100

xviii — indicates that the necessary data for a complete assessment are not available.

xix (Committee on Identification of Critical Minerals, 2023)

xx (Committee on Identification of Critical Minerals, 2023)

xxi (Chadha, R. et al., 2023)

They fall into four categories:

i. **High Demand–High Import Dependence:** Minerals such as nickel, lithium, cobalt, and REEs show high cumulative demand, no reserves and near-complete import dependence (100%). These materials are essential for battery storage, electrolysers, and wind technologies.

ii. **Gaps in Domestic Reserves Data:** In several high-demand minerals (for example, cobalt, vanadium and lithium), resource estimates exist but reserves remain unestablished, creating long-term ambiguity around domestic supply potential. A number of moderate- and low-demand minerals (including tellurium, gallium, germanium and indium) also lack reserve data, highlighting the need for accelerated exploration and improved geological reporting.

iii. **Gaps in Processing and Refining Infrastructure**: Some minerals, such as copper and graphite, have significant domestic resources and reserves yet show moderate import dependence. In silicon, overall import dependence is low, but India remains almost fully dependent on imported polysilicon for manufacturing crystalline silicon wafers used in solar PV. These mismatches suggest gaps in processing capacity, refining infrastructure and economic viability rather than geological endowment.

iv. **Trace and Niche Minerals:** Some minerals (e.g., strontium, gallium, indium, tellurium, germanium) have very low projected demand but are critical to specialised applications in solar PV and electronics. With no reported reserves or resources, these minerals will likely need to be secured through strategic imports or as by-products of other mineral processes.

Domestic Resources and Structural Constraints: India has considerable geological potential across CETMs such as Rare Earth Elements (REEs), cobalt, and nickel. However, translation into economically mineable reserves has been modest due to structural and market factors: evolving exploration frameworks, limited technical expertise, lack of long-term risk capital, and weak incentives for private participation in early-stage exploration. Addressing these barriers could strengthen domestic supply capabilities and reduce long-term import dependence.

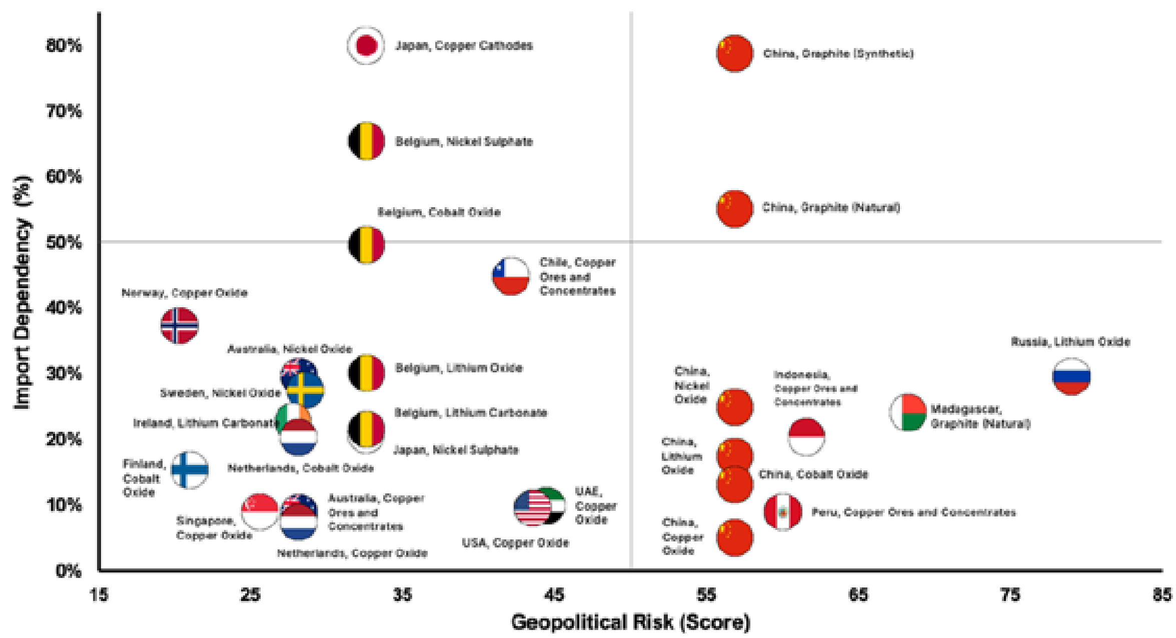
Processing and Refining Capacity: India has good processing capabilities for bulk minerals but limited capacity for CETMs. Copper illustrates both strengths and challenges: large-scale smelting and refining facilities exist (Table 8.3), yet participation is concentrated among a few players, utilisation has fluctuated, and supply disruptions have increased import dependence. New projects such as the 1 Mtpa Kutch copper project could enhance resilience, but long-term competitiveness requires a diversified processing ecosystem.

Table 8.3: Major copper smelting and refining capacities in India

Companies (Indian Bureau of Mines, 2024a)	Company Type	Capacity (kt)
Hindustan Copper Ltd	Government	101.5
Sterlite Industries	Private	400.0
Hindalco Industries Ltd	Private	500.0

Rare earth processing shows similar constraints, dominated by public-sector entities with limited private participation. Unlocking potential will require incentives for advanced separation technologies, risk-sharing mechanisms, and scaling of secondary supply through recycling. Early initiatives in battery recycling and materials recovery demonstrate capability, but scaling requires sustained policy support, feedstock access, and integration with manufacturing demand.

Import Dependence and Geopolitical Exposure: India's high import dependence on geopolitically sensitive regions poses significant risks. Trade flow analysis (FY2019–2023) combined with geopolitical risk indicators highlights concentrated vulnerabilities in cobalt, lithium, nickel, graphite, and copper. Graphite is particularly exposed due to reliance on China, while copper cathodes and nickel compounds show significant single-country exposure despite sourcing from otherwise stable partners. Such concentration increases risks from geopolitical tensions, policy shifts, infrastructure failure, or external shocks. Figure 8.3 illustrates these vulnerabilities by mapping India's import dependency (Y-axis) against the geopolitical risk scores of supplier countries (X-axis), with the top-right quadrant highlighting the most critical exposures.



Source: UN Comtrade, Control Risks, Fragile States Index, IEEFA

Figure 8.3: India's import dependency of key minerals vs. geopolitical risk

Structural Vulnerabilities in Global Supply Chains: Global CETM supply chains exhibit five structural vulnerabilities with direct implications for India.

1. **Foreign ownership** of mineral assets reinforcing global processing dominance (Leruth et al., 2022).
2. **Rising export restrictions** on mineral concentrates as producer countries seek downstream value capture (Przemyslaw Kowalski & Clarisse Legendre, 2023).
3. **Long-term offtake** and equity-linked contracts restricting market access and reducing spot liquidity.

4. **Price volatility** in lithium, nickel, and cobalt, which are essential for a range of clean energy technologies has risen up the policy agenda in recent years. This is driven by rapidly increasing demand, volatile price movements, supply chain bottlenecks, and geopolitical concerns, creating significant financing and investment uncertainty (International Energy Agency, 2024) The dynamic nature of the market necessitates greater transparency and reliable information to facilitate informed decision-making, as underscored by the request from Group of Seven (G7).
5. **Environmental and social risks** in producing regions, including water stress, deforestation, labour rights violations, and weak community consent (Sawal, 2022; Cao et al., 2024;social and economic sustainability risks of cobalt mining, particularly artisanal and small-scale mining (ASM UN Secretary General's Panel on Critical Energy Transition Minerals, 2024).

Addressing these vulnerabilities requires not only diversification of sourcing, but also stronger environmental safeguards, and governance accountability across supply chains.

Domestic Procurement and Downstream Linkages: India's production-linked incentive (PLI) schemes have successfully attracted downstream investment in solar PV, EVs, and batteries. However, they have yet to show an impact on upstream mining and processing. Without stronger procurement linkages or dedicated incentives for mineral processing, downstream growth risks deepening import dependence.

India's CETM supply chains face a convergence of risks: rapidly rising demand, limited certified reserves, underdeveloped processing capacity, high import dependence, and exposure to concentrated global supply chains. While India has significant geological potential and emerging recycling capabilities, structural barriers in exploration incentives, data credibility, processing economics, and international sourcing persist.

8.3 ECOSYSTEM REQUIREMENTS FOR CIRCULAR ECONOMY SOLUTIONS

India's reliance on imported CETMs poses significant vulnerabilities. Recovering CETMs from e-waste and other secondary sources can supplement primary supply and reduce overall material footprint. This section assesses the role circularity can play in meeting India's CETM needs, estimating the volume of e-waste and other secondary sources available for recovery across sectors and technologies. The analysis projects e-waste generation through 2047 and evaluates recycling technologies against technical, economic, and environmental criteria to identify viable pathways for scaling circular-economy practices.

India's evolving regulatory framework including the E-waste (Management) Rules 2011, Battery Waste Management Rules 2022, the National Policy on Electronics 2019, and MSE Scheme for Promotion and Investment in Circular Economy (MSE-SPICE). It emphasises Extended Producer Responsibility (EPR) and aims to build a structured, traceable, and environmentally sustainable e-waste processing ecosystem.

Estimating e-waste available for recycling: Using a five-step methodology (detailed in the Working Group report on Critical Minerals, Volume 10), the study estimates recoverable CETM volumes through 2047. Figure 8.4 presents projected cumulative recoveries from modelled e-waste streams. Copper shows the largest recovery potential, reflecting its widespread use in consumer and industrial electronics. Graphite follows, sourced primarily from end-of-life EV batteries, underscoring the strategic importance of battery recycling. Other high-value battery minerals—nickel, lithium, and cobalt—also exhibit substantial recoverable volumes. Silicon recoveries are moderate, concentrated in end-of-life solar PV modules, while neodymium is recovered in smaller quantities from spent permanent magnets in EV motors and wind turbines.

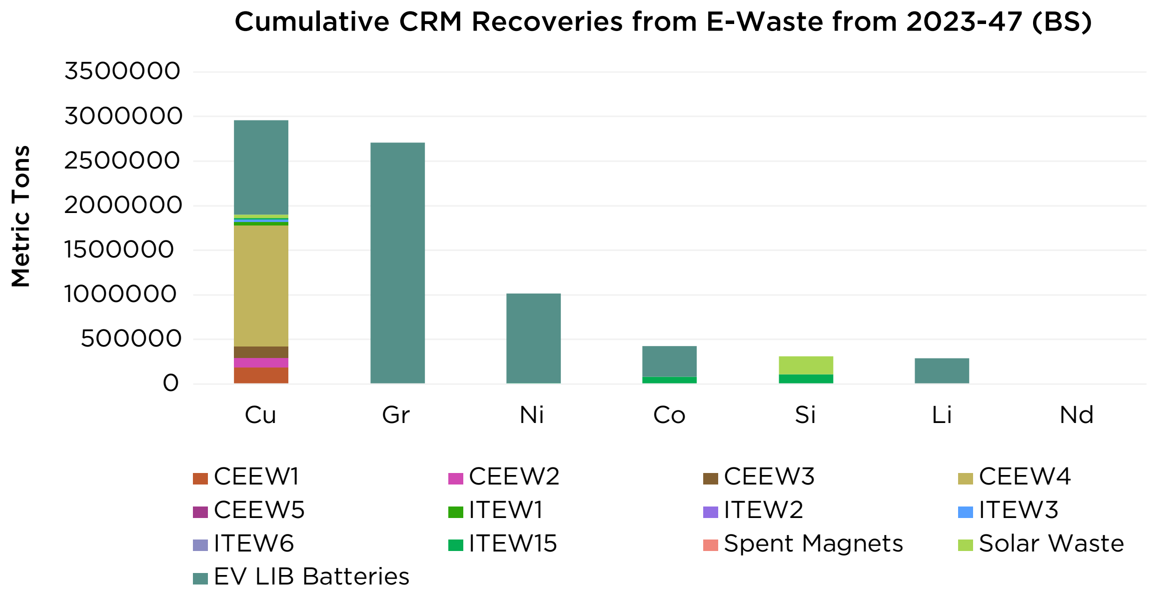


Figure 8.4: Cumulative CRM recoveries from e-waste between 2025 and 2047 in Current Policy Scenario[xxii]

Collectively, these trends indicate a structural shift: recoverable CETMs will increasingly originate from clean-energy technology waste rather than traditional electronics. This requires dedicated collection channels, reverse-logistics systems, and specialised processing facilities tailored to batteries, PV modules, and magnet assemblies. Under an aggressive scenario (85% processing target), recoveries increase by 13.25%.

Recycling technology pathways: The Technology Assessment Framework (detailed in the Working Group report on Critical Minerals, Volume 10) evaluated pyrometallurgy, hydrometallurgy (acid leaching), and hydrometallurgy (bioleaching) against technical, economic, and environmental criteria. Bioleaching ranked highest on environmental and economic grounds due to low capital costs and minimal impacts, while acid-leaching scored best technically for efficiency and maturity. Pyrometallurgy, though mature, ranked lowest across all criteria. These findings highlight hydrometallurgical approaches, especially bioleaching, as promising solutions for scaling environmentally sound and cost-effective recycling in India.

Contribution of circularity to CETM demand: Figure 8.5 illustrates the projected share of CETM demand (2025–2047) that can be met through recycling. Cobalt shows the greatest potential, with recoveries rising from ~30% in 2030 to nearly 100% by 2040, driven by high volume of

xxii CEEW- Consumer Electrical and Electronics Waste (1- TV sets, 2- Refrigerator, 3- Washing Machines, 4- Air Conditioners, 5- Fluorescents and lamps; ITEW - Inormation Technology and Telecommunication Equipment Waste (1- CPU, 2- Desktop, 3- Laptop, 4- Notebook Computers, 6- Printer 15- Cell phones) cobalt-rich batteries reaching their end of life with a simultaneous shift toward lower-cobalt and cobalt-free alternatives in future, reducing overall cobalt demand in the economy. Nickel follows a similar but more gradual trajectory, due to its continued requirement in various technologies.

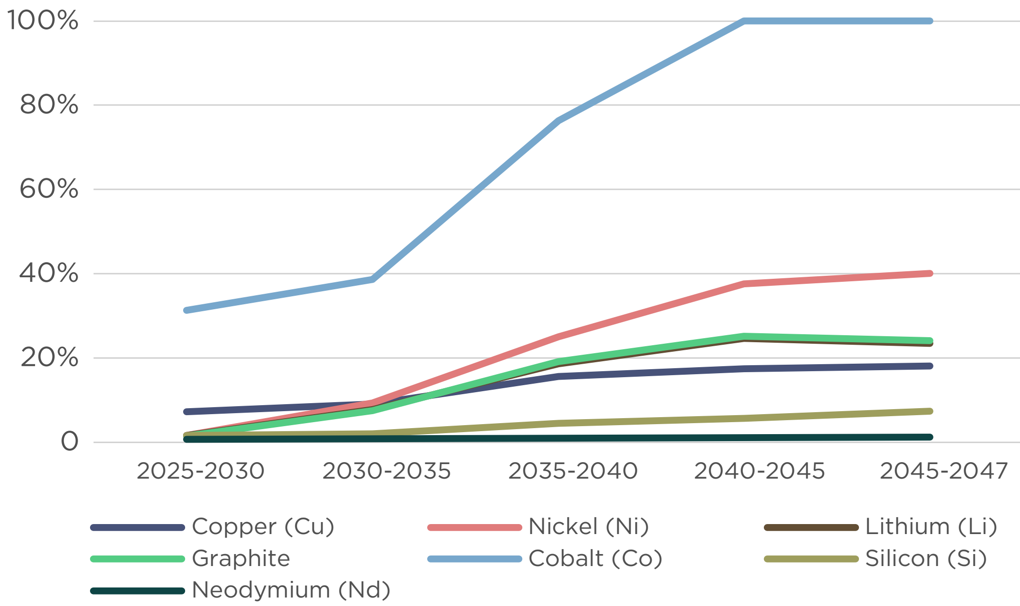


Figure 8.5: Cumulative CETM recoveries from e-waste between 2025 and 2047 in baseline scenario

Graphite, copper, and lithium also show steady increases, reaching around 15-25% by 2047, reflecting growing recycling volumes as battery and electronics waste accumulates. In contrast, recycling contributes to only a fraction of the new demand for silicon and neodymium.

As deployment of low-emission technologies picks up at mid-century, we see the limited ability of recycling to meet demand post mid-century. These trends show that recycling can partly succeed in meeting the needs for select minerals. For most Critical Energy Transition Minerals (CETMs), it may supplement but will not replace primary supply, highlighting the need for parallel investments in mining, processing, waste import, and material efficiency strategies.

Alternative Sources of Minerals: While consumer electronics remain a key focus for mineral recovery, there is significant untapped potential in alternate sources, particularly manufacturing waste from sectors such as automotive, battery production, renewable energy, and mining tailing. They often contain high concentrations of CETMs, are more centralised and compositionally consistent than post-consumer waste, making them more accessible and cost-effective for recovery. Policies must incentivise industries to accurately report, segregate, and direct valuable manufacturing waste into formal recycling systems.

Despite several systemic limitations, e-waste and battery recycling show considerable potential, as yet untapped, to contribute to India's CETM security. Notably, recycling can partially meet the demand for battery-related minerals. For many other CETMs such as silicon and rare earths like neodymium, the expected contribution is marginal.

While scaling up formal recycling systems can help close material loops for select minerals, to realise the full potential of circular economy pathways in India, it must be complemented by i) parallel efforts to improve collection efficiency; ii) investment in advanced recovery technologies; and iii) strengthened regulatory enforcement.

In conclusion, the effectiveness of circular economy as a source must also be viewed through the lens of India's manufacturing trajectory. If India manufactures 20–30% of the low-emission technologies it deploys, the projected levels of material recovery may be adequate to meet much of the domestic demand for key battery minerals while at the same time exposing it to global value chains. However, if India's manufacturing footprint expands significantly, recycling alone will not suffice. In such a case, the country would need to increase primary mineral procurement and actively explore the import of high-value end-of-life products and battery scrap from other regions as an additional feedstock.

8.4 R&D REQUIREMENTS FOR CRITICAL MINERAL PROCESSING AND RECYCLING

Research and development (R&D) is a cornerstone of India's Critical Energy Transition Minerals (CETMs) strategy. This section reviews India's current capabilities in critical mineral processing and recycling, examines the existing policy support for CETM-related R&D, and provides an overview of global research trends that could inform the direction of future domestic efforts.

Technologies for Mineral Processing and Recycling: Comparative analysis of 18 CETMs (detailed in the Working Group report on Critical Minerals, Volume 10) shows India's processing capabilities fall into three categories (Table 8.4):

i. **Mature processes:** Technologies broadly at par with international best practices, supported by pilot-scale demonstrations or established commercial operations.

ii. **Pilot/partial processes:** Pre-commercial technologies limited to beneficiation or intermediate purification, lacking the ability to produce high-purity end-products.

iii. **No domestic processes:** Minerals for which India currently lacks meaningful processing capability at research, pilot, or commercial scale.

Table 8.4: Domestic process maturity in primary and secondary processing, and strategic actions required

Maturity Category	Processing	Recycling	Strategic Action Required
Mature Process	Lithium, cobalt, nickel, graphite, vanadium, tungsten, titanium	Lithium, cobalt, nickel, graphite, vanadium, tungsten, titanium	Prioritise industrial scaling and commercialisation through targeted policy incentives, including PLI-type schemes and scale-up support for refining and recycling capacity.
Pilot / Partial Process	Neodymium, praseodymium, titanium-metal, niobium, tantalum, germanium, tellurium, yttrium, selenium	Indium, niobium, tantalum, gallium	Support scale-up, validation and industrial integration of promising lab-scale processes through translational R&D, public–private consortia, and targeted international technology collaborations.

Maturity Category	Processing	Recycling	Strategic Action Required
No Domestic Process	Terbium, gallium, indium, scandium	Germanium, scandium, tellurium, selenium	Deploy mission-mode R&D, technology transfer agreements, and global partnerships to address strategic dependencies, with a focus on by-product recovery and high-purity separation technologies.

Policy support for R&D in CETM: India's critical minerals R&D ecosystem is anchored by a set of targeted public programmes spanning upstream minerals and downstream recycling. The Ministry of Mines' Science and Technology (S&T) Programme supports applied research across geosciences, exploration, mining, mineral processing, metallurgy, recycling, and resource conservation, with funding extended to academic institutions, national institutes, DSIR-recognised R&D organisations, startups, and MSMEs.

In 2023, this was strengthened through S&T-PRISM (Promotion of Research and Innovation in Startups and MSMEs in Mining, Mineral Processing, Metallurgy and Recycling), creating a dual-track structure covering institutional R&D and startup seed support. In 2024–25, 28 critical mineral–related projects were sanctioned under these two components. Complementing this, the Ministry of Electronics and Information Technology (MeitY) has established India's first Centre of Excellence for E-waste Management at C-MET, Hyderabad. It develops and transfers recycling technologies for printed circuit boards, lithium-ion batteries, rare-earth permanent magnets, fluorescent lamp phosphors, and PV solar cells. These technologies have already been transferred to around 30 industries. Together, these initiatives aim to bridge the gap between innovation and commercialisation and strengthen domestic capabilities across critical mineral and recycling value chains.

Global developments in mineral processing and recycling: Globally, R&D is shifting from incremental optimisation of established methods to next-generation technologies that address efficiency, sustainability, and supply-chain complexity. Key priorities include:

i. **Enhancing resource efficiency**, especially from low-grade or unconventional sources, like mine-tailing

ii. **Reducing environmental impact** through cleaner, less energy-intensive processes

iii. **Unlocking value from secondary sources** via advanced recycling and recovery technologies

Innovation frontiers include:

i. Direct lithium extraction (DLE) from low-concentration brines/clays.

ii. Direct battery recycling to retain material structure; closed-loop processes to cut reagents/waste.

iii. Electrometallurgical/solvent-free extraction powered by renewables; advanced electrowinning/refining for high-purity metals from dilute/complex solutions.

iv. Ion-selective membranes for targeted separations with reduced cross-contamination.

These global innovations present India with an opportunity to leapfrog legacy infrastructure, build decentralised and low-footprint processing systems, and align its CETM roadmap with sustainable materials recovery. By combining domestic R&D initiatives with international technology partnerships, India can strengthen its resilience, reduce import dependence, and position itself at the frontier of clean-energy mineral processing.

8.5 CHALLENGES AND SUGGESTIONS

This section synthesises key findings into a set of interlinked challenges shaping India's Critical Energy Transition Minerals (CETMs) supply landscape, and outlines the strategic directions required to address them. These directions are guided by a coherent set of system-wide principles: (i) enabling private sector leadership across the CETM value chain; (ii) aligning policy interventions with differentiated timelines across domestic, international, and circular supply pathways; (iii) diversifying risk through strategic and mutually beneficial international partnerships; (iv) treating environmental and social performance as a core supply-security requirement; (v) prioritising mission-oriented innovation and leapfrog technologies; and (vi) strengthening institutional capacity, data systems, and Centre–State coordination.

1. Strengthen Domestic Exploration and Mining

Challenge: Domestic CETM viability depends on aligning risk–reward incentives for high-uncertainty exploration, generating decision-grade geological intelligence, coordinating permissions across authorities, and clarifying the operational role of public sector capabilities. Without discovery-oriented, data-driven, and coordination-efficient frameworks, domestic CETM mining will remain slow, episodic, and unable to deliver strategic supply security at scale.

Suggestions:

i. **Rebalance exploration access and licensing pathways** – Conditional First-Come, First-Served (FCFS) access may be introduced for early-stage exploration of priority CETMs with milestones, data disclosure and rights-based progression.

ii. **Make private-sector participation the default for early-stage exploration** – Adopt private-sector award as the default pathway for exploration licences for critical minerals, using conditional First-Come, First-Served (FCFS) mechanisms (preferred over auction) appropriate to geological uncertainty and till market matures.

iii. **Improve geological knowledge and data credibility** – Mandate Committee for Mineral Reserves International Reporting Standards (CRIRSCO), aligned reporting and strengthen pre-competitive geological intelligence for regulatory decision-making.

iv. **Align public-sector mining capabilities with critical minerals priorities** – Review and realign PSU mandates, assets and investment priorities to ensure consistency with national critical minerals objectives.

v. **Preserve environmental and social accountability in project approvals** - Retain public consultation as a targeted risk-screening mechanism, restrict expedited approvals to compliant proponents, and mandate independent audits for fast-tracked projects.

vi. **Improve permitting efficiency and coordination** – Establish coordinated centre–state permitting mechanisms, including Chief Secretary–led committees and digital tracking systems.

2. Build Domestic Innovation and Technology Capability for Critical Raw Materials

Challenge: Technology readiness gaps indicate that CETM supply constraints are as much innovation and scale-up-driven as they are resource-driven. Without tighter alignment between research priorities, pilot-to-commercial pathways, and global technology ecosystems, India's ability to translate resource potential into secure and competitive CETM supply will remain structurally constrained.

Suggestions:

i. **Establish a mission-oriented R&D framework for critical raw materials** – Shift from fragmented projects to outcome-oriented missions aligned with national risk and deployment priorities.

ii. **Create pilot-to-commercialisation pathways for priority technologies** – Shared pilot and demonstration infrastructure are needed for priority processing, refining, and recycling technologies, with transparent access rules for start-ups, MSMEs, and private firms. VGF and other risk-sharing instruments tied to performance benchmarks should be provided for first-of-a-kind deployments.

iii. **Enable structured international technology co-development and absorption** – Pursue joint R&D and pilots while embedding domestic capability-building and localisation requirements.

3. Diversify International Supply Sources and Reduce Import Risk

Challenge: International engagement is unavoidable for CETMs, but resilience depends on how external exposure is managed. Without deliberate strategies to address concentration risk, enable integrated value-chain participation, strengthen execution capacity, and manage market volatility, import dependence may continue to translate into systemic vulnerability.

Suggestions:

i. **Diversify overseas mineral access through risk-differentiated partnerships** – Critical minerals need to be classified by concentration and geopolitical exposure, and their risk profile can be translated into differentiated engagement strategies.

ii. **Embed India in resilient global value-chain arrangements** – Identify minerals suitable for shared processing and refining hubs through bilateral and plurilateral frameworks.

iii. **De-risk overseas access through aggregation and facilitation** – Project preparation support should be established, alongside aggregate demand for equity and offtake, and coordinate overseas engagement through a single-window facilitation platform.

iv. **Strengthen KABIL for overseas CETM execution** – KABIL's execution capacity requires strengthening through calibrated capitalisation, targeted lateral recruitment in international mining and project finance, and prioritised overseas CETM project pipeline. For this, partnerships with overseas-facing PSUs and public financial institutions can leverage their due diligence, negotiation, and asset operation expertise while retaining KABIL's focused CETM mandate.

v. **Reduce market risk through improved price discovery and hedging** – Facilitate access to relevant global mineral exchanges and develop India-linked instruments where required, integrating market signals into sourcing and stockpiling decisions.

4. Scale Circularity and Refining

Challenge: India's CETM supply challenge is fundamentally a midstream challenge. Without parallel progress on circularity, refining economics, technology access, and environmental credibility, upstream resource access and downstream manufacturing ambition will not translate into resilient supply chains.

Suggestions:

i. **Make refining and advanced recycling economically viable** – Deploy a targeted package of capital support, output-linked incentives and tax rationalisation for refining and advanced recycling facilities.

ii. **Secure access to critical refining and recycling technologies** – Facilitate bilateral and plurilateral technology access arrangements with embedded domestic capability-building requirements.

iii. **Unlock reliable secondary feedstock for CETMs** – Permit controlled imports of high-value scrap, enable authorised access to mine tailings and legacy waste, and undertake a national assessment of tailings potential.

5. Institutional Architecture (IA) for National Critical Raw Materials Governance

Challenge: The governance constraints identified indicate that India's critical raw materials challenge is no longer primarily one of individual policy instruments or programme design. There is a need of durable system-level functions that can set strategic scope, assess evolving risks, calibrate execution tools, and steward a small number of system-critical projects across value chains and ministries.

Suggestions:

i. **Establish a national CRM analytical unit for strategy and system-level risk assessment**– Establish a dedicated Critical Raw Materials (CRM) analytical unit to set strategic scope, conduct system-level risk assessments, and develop a periodically updated National Critical Raw Materials Strategy.

ii. **Develop a National Critical Raw Materials Strategy on a recurring basis** - This will consolidate demand signals, integrate cross-sector supply-risk and early-warning assessments, and identify priority raw materials, value chains, and strategic projects.

iii. **Enable strategic project designation, stewardship, and delivery coordination** – Identify a limited set of strategic CRM projects and apply enhanced inter-ministerial and centre–state coordination to resolve bottlenecks, without diluting statutory safeguards

9

SOCIAL IMPLICATIONS OF ENERGY TRANSITION

Social Implications of Energy Transition

9

India's energy transition is more than a technical or economic shift amid increasing climate risks; it is a transformative process that touches land, water, livelihoods, health, and social behaviour. India's pursuit of the twin goals of a developed economy status by 2047 and Net Zero emissions by 2070 hinges on ensuring social and economic equity, expanding opportunities for all, and mobilising investments that drive equity and inclusion. This necessitates a dual approach, balancing ambitious mitigation targets with enhanced adaptation and resilience measures. This chapter highlights the social dimensions of India's energy transition, addressing land, water, livelihoods, health, and behavioural factors.

9.1 LAND AND WATER REQUIREMENTS

India's energy transition is intricately linked to land and water needs, resources that are increasingly getting scarce in a densely populated country. India has only 0.11 hectares of arable land per person, far below the global average of 0.172 hectares, reflecting land scarcity (World Bank, 2023). Adding to this is the growing reality of land degradation arising from the combination of climatic, developmental, social and anthropogenic pressures. Indian Space Research Organisation' (ISRO) Desertification and Land Degradation Atlas of India (2018), reports as of 2018-19, approximately 30% of India's total geographic area (304.02 million hectares) were degraded.

Water stress is also present. Assessments indicate that average annual per capita water availability is projected to drop from 1,486 cubic meters in 2021 to 1,367 cubic meters by 2031, placing India in the "water-stressed" category which is defined as having less than 1,700 cubic meters available per person (Ministry of Jal Shakti, 2024). There are 12 river basins that face per capita water availability below the scarcity threshold (NITI Aayog, 2019). Further, groundwater supports domestic water needs and irrigation amid intensifying economic and urban growth demands. Climate change is further increasing these pressures through erratic monsoons, increased rainfall variability, and rising temperatures. While water pollution remains a significant concern, despite marked improvements over the years (Central Pollution Control Board (CPCB), 2025).

Land and water are important for the country's development, infrastructure, urbanisation, and housing in addition to meeting agriculture requirements. The expansion of renewables further intensifies existing pressures on these resources. These competing demands and trade-offs need to be managed very carefully to ensure a smooth and inclusive transition.

Projections and Trends

India's Net Zero and Current Policy Scenarios entail substantial land and water requirements for clean energy deployment. Figure 9.1 presents land requirements (in million hectares) for 2030, 2050, and 2070 under both the scenarios.

In terms of future assessments, land demand for the power sector increases steadily under both scenarios as renewable capacity expands. Under the Current Policy Scenario, land requirements are projected to rise from 0.68 million hectares (Mha) in 2030 to 2.35 Mha in 2050, reaching approximately 4.2 Mha by 2070. Under the Net Zero Scenario, land requirements are substantially higher, increasing from 0.82 Mha in 2030 to 3.26 Mha in 2050, and reaching 5.92 Mha by 2070. This reflects the extensive deployment of solar, wind, and nuclear energy required under a rapid low-carbon growth pathway. Future adoption of rooftop solar, floating solar, and agro-photovoltaic systems could, however, diversify deployment models and partially mitigate land pressures.

At the national level, the aggregate land requirement for clean energy deployment appears manageable relative to India's total geographic area of approximately 300 million hectares. Recent land-use statistics indicate that net sown area constitutes 46.20% of the total area, while current and other fallow lands account for 8.35%. Pastures, tree crops, and culturable wastelands collectively represent 6.15% (Directorate of Economics and Statistics, Department of Agriculture & Farmers Welfare, 2024). Further, wastelands constitute only ~17% of the total land area, estimated at 55.76 million hectares in the Wasteland Atlas of India (2019). A large part of this is India's open natural ecosystems (Vanak, and Madhusudan, 2022). Large-scale renewable projects are often set up on these wastelands. In reality, these open ecosystems often support grazing, biodiversity, and rural livelihoods (Vanak & Madhusudan, 2022).

As observed, land requirements for the power sector under both the scenarios is projected to increase over the years. This is majorly driven by the increasing share of renewables. Under the Current Policy Scenario, the land requirements are projected to reach 4.2 Mha by 2070, which is equivalent to about 7.5% of the assessed wastelands. Further, under the Net Zero Scenario the land requirements are projected to reach 5.92 Mha by 2070, which is equivalent to about 11% of the assessed wastelands. In both the scenarios the wasteland estimates for clean energy deployment constitute a substantial portion of the available wastelands. Given this, the diversion of such ecosystems for setting up large-scale renewable energy projects necessitates rigorous safeguards to mitigate socioeconomic and ecological impacts.

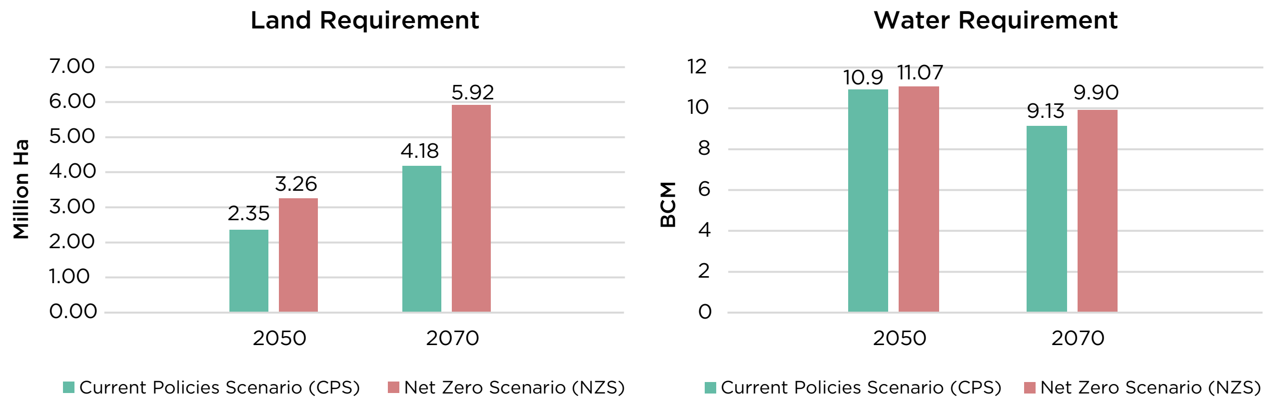


Figure 9.1: Land requirement (Mha) and water requirement (BCM) across Current Policy Scenario and Net Zero Scenario till 2070

Concurrently, water requirements of the power sector evolve differently across scenarios as the generation mix shifts (Figure 9.1).

Under both the scenarios, water consumption increases substantially by mid-century and declines thereafter, driven by the rising share of renewables, which have low operational water requirements. It is further noted that the water consumption in the Net Zero Scenario remains higher than the water consumption under the Current Policy Scenario throughout. This is due to greater nuclear capacity and the scaling up of green hydrogen production under the Net Zero Scenario (Figure 9.1).

The increase in water use also has to be evaluated in the context that the rapid expansion of renewable energy infrastructure is unfolding in regions experiencing hydrological constraints. Groundwater over-exploitation affects over 25% of administrative units in several states, with renewable zones increasingly coinciding with “Critical” and “Over-exploited” districts (Central Ground Water Board, 2025).

Moreover, renewables create indirect resource pressures along their value chains. Grid expansion (transmission corridors and substations) adds to land footprints (besides the estimates in Figure 9.1), while battery storage depends on minerals such as lithium, cobalt, and nickel, whose extraction is water-intensive. Lithium extraction uses 1.9-2.2 million litres of water per tonne of lithium (Greenmatch, 2024). Nickel mining, often from laterite ores, can impact natural ecosystem (Genchi et al., 2020).

Spatial Aspects of Transition

India’s land and water resource needs for renewable energy expansion needs to be seen in the context of demographic growth, ecological considerations, and multiple development priorities. This needs a closer examination of trajectories, including their geographic distribution, intersections with prevailing land uses, and other conditions.

India’s renewable energy reforms have accelerated utility-scale solar deployment alongside wind and solar hybrids through several reform measures such as the Payment Security Mechanism, Waiver of Inter-State transmission charges, 100% FDI under the automatic route, the Green Energy Corridors programme, etc.

India's renewable energy reforms have resulted in ~100 GW of solar installed capacity, alongside 135 GW under construction. Wind power constitutes more than 50 GW of the installed capacity, with over 30 GW under various stages of development (PIB, 2025).

While these measures have facilitated rapid scale-up, they have also created conditions favouring large, contiguous sites in resource-rich zones. Nearly 75% of installed solar and wind capacity is geographically concentrated in arid and semi arid regions of majorly: Gujarat, Rajasthan, Maharashtra, Tamil Nadu and Karnataka (MNRE, 2025).

Suggestions:

1. **Technological Innovation and Decentralised Renewable Energy (DRE) systems** offer pathways to decouple renewable deployment from competing uses of land and water. Decentralised Renewable Energy (DRE) systems such as rooftop solar, mini-grids, solar pumps, and street lighting can be prioritised as their deployment extend access without large-scale land acquisition, directly supporting rural livelihoods and last-mile electrification. Such models enable inclusive access, local ownership, and equitable benefit-sharing.

   Implementation of DRE through Renewable Energy Service Companies (RESCOs) can be leveraged for aggregation via land leases and revenue-sharing. This approach may be a preferred model as Farmer Producer Organisations may lack technical expertise for managing distributed renewable energy projects at scale.

   Similarly, agrivoltaics, floating solar, and built-environment integration demonstrate that energy expansion need not displace existing productive land use while preserving agricultural output and reducing water consumption. To scale these models, there is a need to address the premium costs associated with these technologies. Accordingly, pursuing these options requires targeted viability-gap support or concessional debt to socialise the land-benefit while keeping retail tariffs stable. Additionally, for floating solar, comprehensive reservoir mapping through the Central Water Commission and state irrigation departments may be undertaken to identify suitable areas.

2. **Spatial Planning** for renewable energy development may systematically adopt tools such as the Integrated Biodiversity Assessment Tool (IBAT) and the Avian Sensitivity Tool for Energy Planning (AVISTEP) to identify and avoid ecologically sensitive habitats. The planning process may focus on repurposing degraded, mining-affected, or post-industrial lands for energy projects, thereby minimising adverse environmental and social impacts while supporting resource efficiency.

3. **Water Governance:** Currently, energy production is captured under 'industry' in national and state water policies. Bringing energy explicitly into these policies enables rational priority-setting and efficiency optimisation. Safeguards while prioritising allocation for energy may include:

   - For coastal zones, the integration of desalination technologies offers a pathway to reduce freshwater requirements.
   - In regions facing acute groundwater depletion, the focus may shift toward circularity utilising treated wastewater for energy production.

- Prioritize water-lean technologies by incorporating efficiency as an evaluation criteria, rewarding waterless cleaning or closed-loop recycling.

9.2 EMPLOYMENT AND MIGRATION: A WORKFORCE IN FLUX

India's demographic profile represents a defining structural advantage for its development ambitions and integration into global value chains. With a median age of about 28 years and a workforce exceeding 600 million (FY 2023–24), India is one of the youngest large economies globally, in sharp contrast to ageing trends across most developed nations (UNFPA, 2025). This demographic dividend is expected to persist over the next two decades, providing a sustained supply of working-age population as labour constraints tighten elsewhere.

India has over 370 million people aged 18 to 29, which is around 27% of the population. They are projected to contribute to nearly a quarter of global workforce growth over the coming decade. This enhances India's attractiveness as an investment destination and supporting its ability to deliver infrastructure, manufacturing, and low-carbon projects at globally competitive costs with a workforce adaptable to green and digital sectors.

However, this demographic advantage must be converted into a workforce advantage to realise India's aspiration of becoming a developed economy by 2047. While India produces over two million Science, Technology, Engineering, and Mathematics (STEM) graduates annually and hosts the world's third-largest startup ecosystem, only 5–7% of the working-age population currently receives formal vocational or technical training, much below levels in advanced economies such as Germany or South Korea.

Compounding this is the high degree of labour market informality. Periodic Labour Force Survey (PLFS, 2023-24) estimates that over 70% of non-agriculture workers are informally employed nationally (MoSPI, 2024). Against this backdrop, the employment implications of India's low-carbon transition acquire particular significance. Energy systems are not only central to economic growth but also anchor livelihoods across regions, value chains, and skill levels, making the design of an inclusive transition a core development challenge rather than a sectoral concern.

India's development and low-carbon transition unfolds along with shifts in work, livelihoods, and migration patterns.. States enter this dual transition with markedly different economic structures, labour markets, and exposure to climate and transition risks, shaping how shocks are absorbed and where new employment opportunities emerge.

States can be broadly grouped into agriculture-dominant, industry-led, services-driven, and a few states with diversified sectors. This diversity makes a one-size-fits-all transition unviable, underscoring the need for region-specific strategies.

India's economic structure, as reflected in the state-level typology, is not only uneven across sectors and regions but is also deeply intertwined with the fossil fuel economy. Coal, oil, and gas have historically underpinned industrialisation, electricity supply, and energy-intensive manufacturing, particularly in mining-driven and heavy-industry-oriented states. This legacy has produced pronounced regional concentrations of fossil fuel dependence, where entire regions rely on coal mining, thermal power, refineries, steel, cement, and fertiliser industries for both employment and public revenues.

Over 150 districts across India are significantly dependent on fossil fuel supply chains, directly or indirectly sustaining livelihoods for nearly one-third of India's population (See Figure 9.2) (Bhushan and Banerjee, 2021). This spatial clustering means that the transition away from fossil fuel assets is not an abstract national challenge; it will be a lived reality in specific belts, where jobs, state finances, and induced economies are interwoven with fossil energy.

Coal mining and coal-based power generation together anchor a large share of India's fossil-fuel employment. Formal coal mine employment is estimated at about 3,45,000 workers, with informal employment at least twice as large, implying that over one million people depend directly on coal mining. Coal-based thermal power plants add another major layer, supporting roughly 4,20,000 jobs nationwide when formal and informal employment are combined. In both mining and thermal power plants (TPPs), informal workers namely contractors, transporters, and service providers, constitute the most vulnerable segment.

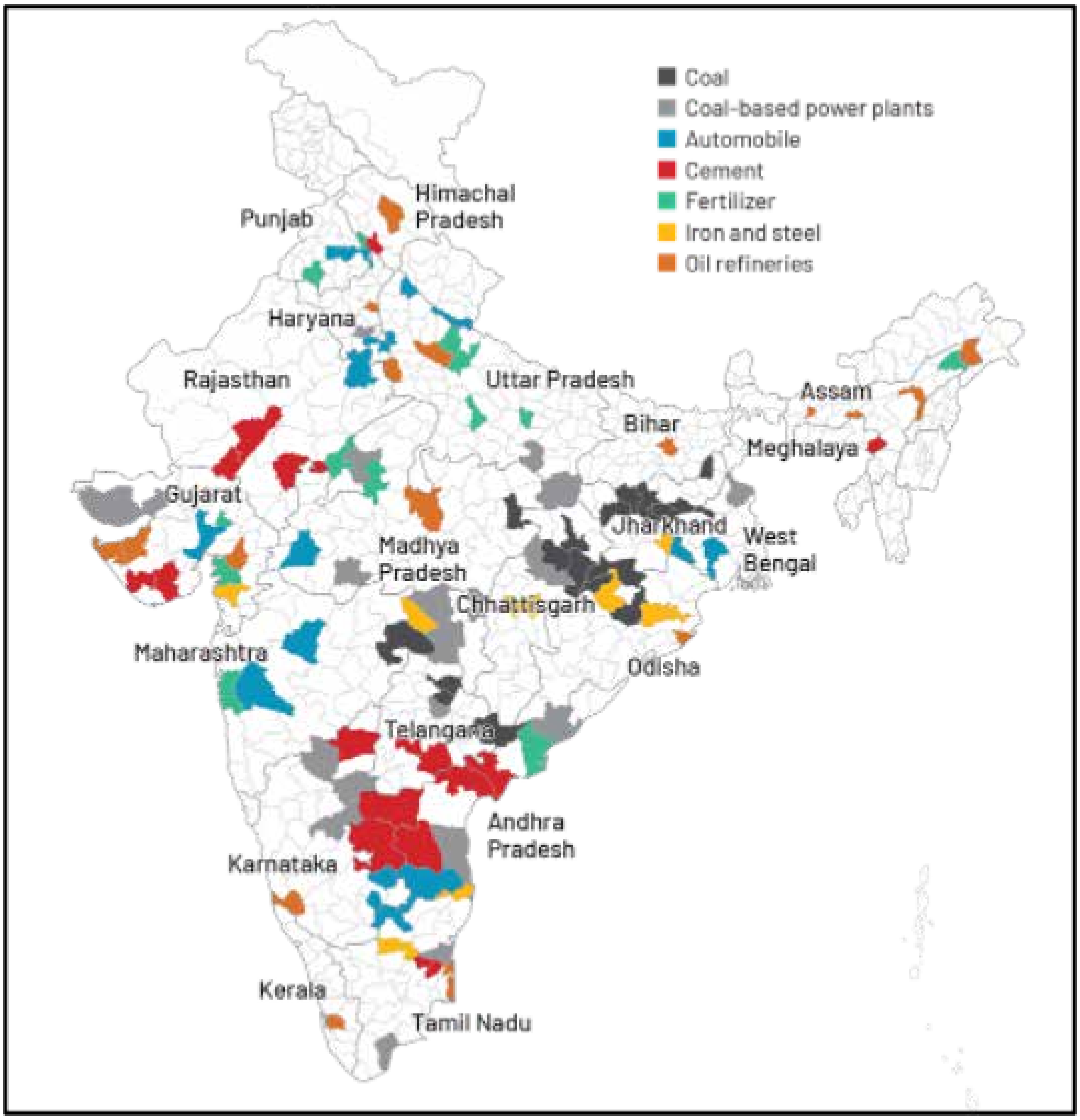


Figure 9.2: Districts dependent on fossil-based economy

Beyond mining and power, fossil-linked manufacturing industries employ a far larger workforce and face more gradual but equally profound transition risks. Sectors such as cement, steel, textiles, petroleum products, chemicals and automobiles together employ nearly 17 million workers, over half of them informal, and are geographically concentrated in the same coal- and power-intensive states. Unlike mining and thermal power, these sectors face disruption through technological substitution such as green steel, low-carbon cement and electric mobility, requiring large-scale reskilling and industrial restructuring to protect livelihoods during the low-carbon transition.

Projections: The Shape of Workforce Transition

Employment impacts are assessed leveraging inputs from the Macroeconomic Working Group Report to analyse labour market changes under both the Current Policy Scenario (CPS) and the Net Zero Scenario (NZS). In the Current Policy Scenario (CPS), the broad employment pattern in the energy sector largely remains stable in 2022 with employment of 6 million by 2050. Coal, oil, gas and electricity account for the bulk of employment. By 2070, total jobs are projected to go to 4 million primarily due to improvements in energy efficiency and technological progress. As the economy becomes less energy-intensive, fewer workers are required both in direct energy production and in the upstream and downstream sectors that supply or depend on energy, leading to a gradual contraction in employment.

However, in the Net Zero Scenario (NZS), industry is projected to record higher employment than the Current Policy Scenario (CPS), for both skilled and unskilled workers, reflecting rising demand from clean technology manufacturing and renewable energy infrastructure. With rapid expansion in clean energy, energy sector jobs are expected to increase to 7 million by 2050 (1 million higher than in the CPS) and 4.5 million in 2070 (0.5 million higher than in the CPS). These results are consistent with the IEA's World Energy Employment 2024, which projects India's energy jobs to grow by over 20% under its stated policies scenario, driven largely by clean energy deployment.

Beyond the energy sector, the Net Zero transition can deliver substantial economy-wide job gains under supportive policies. Job creation is concentrated in construction, road transport, and trade. Under the optimistic scenario[xxiii], construction emerges as the single largest contributor, projected to add about 4.6 million jobs by 2050, compared to the Current Policy Scenario. This is driven by the labour needs of utility-scale RE build-out, grid expansion, and low-carbon infrastructure.

Employment in road transport and trade also grows, with road transport projected to add 67,000 additional jobs in 2050 compared to the Current Policy Scenario. Trade contributes a cumulative 5.2 million additional jobs over the Current Policy Scenario during 2030–2070. This demonstrates that the Net Zero transition can be a major engine of employment outside the energy sector when combined with targeted complementary policies.

Taken together, these projections show that the transition can be a net engine of job growth, not just in the energy sector but across the broader economy. However, geographic mismatches between regions will require deliberate policies for worker relocation, reskilling, and social protection to ensure that the benefits of transition are inclusive and equitably distributed.

xxiii Net Zero Scenario wherein financing source is foreign, incremental finance is unproductive and subsidies are provided for deployment of clean energy protecting the low-income households. For details refer to report on Macroeconomic Implications (Vol. 2).

Suggestions:

i. Develop a national policy framework for worker retraining, relocation support, and economic diversification in districts likely to be affected by industrial decline. The District Mineral Foundations alongside Skill India Mission and Skill Council for Green Jobs may be leveraged to fund and support transition of workers into green sectors.

ii. Based on the national policy framework, integrated district-level transition plans may be formulated for high-risk regions. These plans may combine economic diversification, infrastructure investment, and workforce support to foster locally anchored growth and reduce fossil fuel dependence.

iii. e-Shram may be upgraded to capture sectoral affiliation, contract type, geolocation including migration status, and skill levels, thereby linking informal occupations to fossil-linked industries.

iv. Social protection entitlements for informal and contract workers in transition contexts may be accelerated, ensuring wider accessibility of schemes such as Employees' State Insurance Corporation (ESIC), health insurance, and pension programmes for those facing displacement or income loss.

v. Dedicated transition facilitation units may be established at the local level to support worker registration, benefit access, grievance redressal, and scheme coordination, with targeted outreach to women and other marginalised worker groups.

vi. Sector-specific transition skill roadmaps may be accelerated to identify at-risk occupations in fossil fuel-linked and carbon-intensive sectors and map reskilling pathways into low-carbon roles. At the state-level, skilling initiatives may be aligned with sectoral low-carbon growth roadmaps, specifying occupations and competencies for renewables, grid modernisation, electric mobility, energy efficiency, and climate-resilient sectors.

vii. Implementation of the newly notified labour codes may prioritise high-migrant sectors through accelerated rollout, focused inspections, and enhanced compliance monitoring. This strengthens occupational safety, wage protection, and working conditions in construction, small manufacturing, logistics, domestic work, and gig-based services. Enforcement mechanisms may further adapt to informality, subcontracting, and platform-based employment models that disproportionately affect migrant workers.

9.3 HEALTH: VULNERABILITIES, REGIONAL PATTERNS, AND TRANSITION

India's public health outcomes are increasingly influenced by the intersecting pressures of environmental degradation and climate change. Intensifying heatwaves, worsening air pollution, and more frequent extreme weather events are driving a rise in disease burdens, while indirect impacts, such as the spread of vector- and water-borne diseases, and mental health challenges, further strain health systems. The ongoing energy transition adds a complex dimension, bringing both new risks and opportunities for public health, with impacts varying significantly across regions and population groups. Effectively navigating these challenges will demand climate-informed health strategies that strengthen systemic resilience, foster equity, and unlock co-benefits across sectors.

Vulnerabilities

India's public health outcomes face mounting pressures from climate change arising from the intersection of environmental hazards, social and economic inequality, demographic profile, and the capacity of local systems to absorb shocks.

Direct Climate Health Impacts: Rising temperatures and recurring heatwaves pose India's most acute climate health threat. According to data from the National Centre for Disease Control (2024), there were 48,156 suspected heatstroke cases in 2024. A total of 430 heatstroke related deaths (comprising 161 confirmed and 269 suspected) were reported nationwide in the same year.

Urban Heat Island effects, where cities trap heat during the day and release it at night, thus increasing nighttime temperatures, further compounding risks in densely populated cities. The rise in very warm nights is most noticeable in districts with a large population (over 10 lakh), which are often Tier I and II cities (Prabhu et al, 2025). Over the last decade, nearly 70% of districts experienced an additional five very warm nights per summer (March to June). By 2050, 50% of India's population is expected to live in urban areas (UN-DESA, 2018). Heat island effects therefore pose a serious threat to the population as it can lead to a higher incidence of heat-related illnesses and cardiovascular morbidity, especially among infants, the elderly, and those residing in inadequately ventilated settlements (Romanello et al., 2025). The Ahmedabad Heat Action Plan demonstrates direct correlations between heatwave intensity, duration, and mortality spikes, urging city-level interventions.

In addition, extreme weather events, including floods and cyclonic storms, are increasing and are known to inflict health impacts. This often precipitates mass displacement, injury, loss of essential healthcare access, and outbreaks of water and vector-borne diseases, and economic losses (Roxy et al., 2017). The Emergency Events Database (EM-DAT) pertaining to natural disasters and their related damage costs for the period 1990-2022 shows that India was among the worst affected countries in the world. The data further suggests that floods and storms featured as the top two natural disasters in India between the same period and accounted for the highest share of damage costs at 63.10% and 31.52% respectively (Goldar et al., 2024).

India's air pollution challenge is inseparable from its climate change trajectory. In 2019, air pollution was associated with approximately 1.67 million deaths, with ambient particulate matter acknowledged as a primary driver of both acute and chronic respiratory illness, leading to 0.98 million deaths (Pandey et al., 2019). Climate change is projected to increase this burden through longer pollen seasons, increased ozone and allergen production, and synergistic effects of heat stress and air toxicity.

Indirect Climate Health Impacts: Climate change is expanding the spatial and temporal distribution of vector-borne diseases such as malaria, dengue, and chikungunya (MoEFCC, 2023). Incidents of malaria have been reported in the Himalayas, while dengue now spreads year-round, with a 13% and 53% rise in transmission potential for Aedes aegypti and Aedes albopictus mosquitoes, respectively. Coastal Vibrio pathogen risk has surged by 66%, threatening 23 million people (Lancet Countdown, 2024). The spread and persistence of these infections are compounded by the constraints in vector control and changing human migration patterns.

Climate change further threatens progress in food safety and nutrition across India (Basu et al., 2022). Further, it imposes a significant mental health burden through direct psychological trauma from cyclones, floods, and heatwaves. This is alongside chronic psychopathology such as anxiety, depression, and trauma-related disorders stemming from environmental degradation, economic insecurity, and displacement (Ministry of Health & Family Welfare, 2024).

The growing frequency and severity of climate events threaten the operational resilience of India's health infrastructure. Healthcare systems in more than 40% of Indian districts are at high climate-induced risk (CEEW and UNICEF, 2025). Over 2,00,000 public healthcare facilities are vulnerable to extreme climate events such as floods and cyclones. It increases vulnerabilities in districts, hindering equitable service delivery.

Climate events drive internal migration, displacing over five million people in 2024 from floods, droughts, and storms (IDMC, 2025). Migrants from coastal, riverine, and drought-hit areas often lose public health entitlements upon relocating to peri-urban or urban zones, disrupting children's vaccination schedules and schooling. Women and girls experience additional vulnerability, unequal resource access, and pressure from climate-related migration (M S Swaminathan Research Foundation, 2024).

Current Policy Landscape

India actively addresses climate-health risks through an evolving framework anchored in the National Action Plan on Climate Change (NAPCC) and State Action Plans on Climate Change (SAPCC), integrating adaptation across health, water, agriculture, and energy. The National Programme on Climate Change and Human Health (NPCCHH) mandates district assessments, climate surveillance integration, gender strategies, and nationwide State Action Plans on Climate Change and Human Health (SAPCCHH).

Over 20 states and 100 cities implement Heat Action Plans with meteorological alerts, complemented by NDMA's Sachet protocol and drills under the Disaster Management Act, 2005. The National Clean Air Programme (NCAP) is a time-bound, national strategy targeting a 40% reduction in particulate matter concentrations by 2026 in 131 identified non-attainment cities. While the India Cooling Action Plan (ICAP) aims to provide sustainable cooling and thermal comfort for all by FY 2037-38. The targets include reducing cooling demand, refrigerant demand, and cooling energy requirements, alongside training of service technicians. In addition, the National Mission on Sustainable Agriculture provides the policy anchor for climate-smart agriculture, resource conservation, and organic and natural farming. Further, India's disaster preparedness framework is regulated through NDMA guidelines and statutory provisions in the Disaster Management Act.

Suggestions:

i. **Standardised Vulnerability Assessment and Surveillance:** A single, robust vulnerability assessment framework may be established to provide a consistent national foundation for risk prioritisation. Under NPCCHH leadership, it can incorporate internationally recognised risk models like the IPCC AR5, customised to Indian district realities, ensuring standardisation across states.

   This standardised framework can be integrated into district-level surveillance systems across National Health Mission (NHM), Integrated Disease Surveillance Programme (IDSP), and NPCCHH modules. This can ensure digital tracking of climate-sensitive diseases with mandatory gender, age, and migration disaggregated reporting.

ii. **Strengthen Climate-Resilient Health Infrastructure:** Indian Public Health Standards (IPHS) may be revised to include climate-proofing specifications for all new and existing facilities in high-risk districts. These specifications can address backup power, water security, cooling systems, and elevated designs in flood-prone areas, building on NPCCHH's foundational guidelines.

Further, a real-time climate resilience monitoring system may be integrated with IDSP and NHM to track infrastructure readiness and service continuity metrics. This will enable NPCCHH to effectively safeguard healthcare functionality during extreme weather events.

iii. **Strengthening the Health Workforce:** Climate–health and emergency preparedness modules may be mainstreamed across accredited medical and public health curricula. These can be complemented by periodic refresher training and mandatory preparedness drills for the health workforce and facility managers.

These drills may be institutionalised as a routine operational requirement and linked to annual IPHS accreditation, shifting NPCCHH capacity-building from awareness to action-oriented preparedness.

iv. **Financing Aligned to Climate Risk:** Earmarked NHM funding may be used as a catalytic lever to blend multilateral and philanthropic finance. This may crowd in larger-scale investment for climate-resilient health infrastructure. Further, targeted climate-health insurance pilots may be launched for low-income, disaster-prone populations, leveraging NHM administrative networks.

9.4 BEHAVIOUR: PATTERNS, BARRIERS, AND OPPORTUNITIES FOR CHANGE

India's energy transition will be shaped not only by how energy is produced, but increasingly by how it is demanded and used. While clean technologies and efficiency improvements are essential, their impact depends critically on how household and firm behave in adopting new technologies, adjusting consumption, and responding to price signals. Behavioural barriers such as upfront cost sensitivity, limited trust in new technologies, social norms, and rebound effects can dilute the benefits of supply-side investments. Integrating behavioural insights into policy design is therefore essential to guide choices, shape demand, and sustain low-carbon practices at scale.

India's approach to sustainable development is deeply rooted in a civilisational ethos of mindful production and consumption, where prosperity has traditionally been pursued in harmony with nature rather than through excess. This perspective, now formally articulated through PM Mission LiFE (Lifestyle for Environment) articulated by the Hon'ble Prime Minister, elevates sustainable living from a policy instrument to a foundational development principle. Global evidence reinforces the validity of this pathway – Costa Rica has achieved has comparable longevity with the US (80.8 years versus 78.3 years in 2023) with barely one-fifth of the per capita income through preventive healthcare, community cohesion and active lifestyles. These examples demonstrate that high human development need not follow high-consumption trajectories, opening space for India to advance an alternative model of growth anchored in its civilisational wisdom and climate-conscious practices.

This ethos continues to manifest in contemporary Indian lifestyles that inherently align with low-carbon development. Traditional homes built with local materials, natural ventilation and passive cooling consume far less energy than the globally prevalent glass-and-steel structures dependent on artificial climate control. Multi-generational households, long a feature of Indian society, reduce per capita energy and material demand, particularly in dense urban environments. Dietary practices also reinforce this advantage – according to the Pew Research Center (2021), nearly 39% of Indian adults identify as vegetarian, with many others limiting meat consumption for cultural, religious or health reasons, resulting in diets that are both climate-friendly and health-supportive.

Mission LiFE builds on these lived practices, giving them contemporary policy expression and scale, and positioning India to demonstrate that development, equity and sustainability can be mutually reinforcing rather than competing objectives. It also builds on the demonstrated success of earlier large-scale behavioural programmes such as Swachh Bharat, UJALA, Jal Jeevan Mission and Give It Up, which transformed social norms through nudges, defaults, and social proof rather than mandates alone.

Challenges and Suggestions

Entrenched Travel Habits and Status-Driven Vehicle Ownership: The transport sector faces deeply embedded behavioural barriers to modal shift. Personal vehicles remain symbols of status and autonomy, while public transport is associated with inconvenience and lower social standing. Commuters exhibit strong habitual preferences for private vehicles, reinforced by social norms that equate car ownership with economic success. Electric vehicle adoption encounters behavioural obstacles including range anxiety, technology scepticism, and reluctance to change established routines despite improving performance metrics and government incentives.

Suggestions:

i. **Leverage visible community leadership and peer endorsements** through campaigns showcasing respected community members, technology executives, and public officials using public transport regularly. The Personal2Public campaign in Bengaluru demonstrated how Ministers and corporate leaders taking metro services twice weekly catalysed broader modal shift, creating social proof that sustainable transport choices are compatible with professional success.

ii. **Address misconceptions through targeted testimonial campaigns** featuring peer experiences to counter scepticism about public transport reliability and EV performance, focusing messaging on specific concerns like comfort, safety, and time efficiency rather than generic environmental appeals.

iii. **Integrate behavioural nudges in digital platforms** by designing ticketing applications with default options favouring sustainable modes; mobility apps could display public transport options first, require additional clicks to access private vehicle alternatives, and show comparative journey times with externalities factored in. The broader recommendations are further discussed in the report on the Transport sector.

Behavioural Inertia and Information Gaps in Building Sector: Building occupants and owners display pronounced inertia in adopting energy-efficient practices due to established habits, unclear information, high upfront cost, and perceived inconvenience. The split incentive problem compounds behavioural barriers, particularly in rental settings where efficiency investment costs fall on landlords while energy savings accrue to tenants. Efficiency improvements can generate rebound effects consistent with the Jevons Paradox, wherein households increase usage intensity. Moral licensing further weakens outcomes, justifying less sustainable practices after one pro-environmental action.

Suggestions:

i. **Enable transparent energy performance disclosure** through improved BEE Star Ratings or other suitable indicators to empower market participants with energy cost information, creating salient market signals.

ii. **Deploy personalised efficiency nudges** using smart building systems for contextualised reminders, such as 24-degree thermostat defaults, switching off unused equipment, and optimising natural lighting; promote Time-of-Day tariffs for efficient use.

iii. **Pair efficiency programmes with consumption-awareness** messaging that highlights usage norms and cumulative impacts to address rebound and moral licensing effects.

The broader recommendations are further discussed in the reports on the Building and Power sectors.

Weak Behavioural Signals for Sustainable Procurement in Industry: Hard-to-abate sectors, including steel and cement lack strong behavioural cues for low-carbon choices. Procurement decisions prioritise cost over carbon intensity, with social and environmental factors playing minimal roles. Absence of standardised carbon footprint labelling makes informed low-carbon choices difficult.

Suggestions:

i. **Deploy standardised Product Carbon Footprint** labelling with clear, comparable carbon labels for emission-intensive materials like cement, steel, aluminium, textiles, and chemicals, focusing initially on business-to-business contexts such as procurement portals and construction tenders.

ii. **Expand recognition platforms** by creating sector-specific carbon intensity benchmarks, enhanced with gamification and public recognition.

Risk Aversion and Limited Social Proof in Agriculture: Farmers exhibit behavioural reluctance towards climate-smart practices due to risk aversion, limited exposure to successful implementation, and entrenched traditional methods. Social proof and trusted networks significantly influence decisions, yet visible demonstrations remain scarce.

Suggestions:

i. **Design bundled discounts on climate-smart packages** like drip and sprinkler irrigation or drones through cooperatives or schemes to reduce decision fatigue and improve affordability.

ii. **Encourage and recognise public commitments via platforms** like farmer producer organisations, gram sabhas, or digital pledges, especially for women-led groups; the JEEViKA programme in Bihar exemplifies women self-help groups championing clean energy adoption. Enable farmer-led demonstration plots like Agri-PV to establish visible success stories using peer educators and local leaders.

Limited Consumer Engagement and Awareness of Impact in Electricity Sector: Consumer engagement with demand response should be increased. Households and businesses underestimate their influence on consumption patterns, leading to behavioural inertia. Energy system complexity obscures links between individual actions and environmental impacts.

Suggestions:

i. **Deploy comparative energy reports** with neighbourhood baselines through monthly household reports; Vidyut Rakshaka in Bengaluru achieved 7 % consumption reduction across 2,000 households.

ii. **Create smart meter feedback loops** via mobile apps with real-time insights, tips, and alerts. Implement default green appliance scheduling during high renewable periods. Highlight collective achievements in concrete terms like CO_2 avoided to foster community impact.

Weak Implementation Architecture and Limited Scalability: Progress toward mobilising one billion citizens by 2028 under Mission LiFE needs clear metrics. Behavioural interventions under Mission LiFE need to be supported by baseline data, control groups, or longitudinal tracking, with the ability to distinguish symbolic participation from sustained behavioural change.

Suggestions:

i. **Mainstream Mission LiFE across government programmes** by integrating principles into schemes for housing, energy, transport, water, agriculture, and livelihoods, recognising women's roles.

ii. **Institutionalise outcome-oriented M&E** with behavioural indicators tracking adoption and impacts via research partnerships. Mandate baseline data, controls, longitudinal tracking, and a national repository with flexible protocols.

iii. **Leverage social norms through community leaders** and peer networks, as in Swachh Bharat Abhiyan. Strengthen inter-ministerial and centre-state coordination via review mechanisms.

The demand, supply, and cross-cutting behavioural interventions articulated above exemplify how behavioural insights serve as vital complements to technological and infrastructure measures in India's pathway towards sustainable energy.

10

ENABLING THE NET ZERO TRANSITION: CHALLENGES AND OPPORTUNITIES

Enabling the Net Zero Transition: Challenges and Opportunities

10

This final chapter brings together the insights of all sectoral and cross-cutting working groups to identify what India may do to deliver a credible, affordable, and Viksit Bharat-aligned Net Zero pathway. It distils the detailed sectoral analysis into system shifts, institutional reforms, and investment architecture to ensure that India's transition is smooth, fair, and future-ready.

India's Net Zero pathway is framed as a development strategy, one that prioritises prosperity, resilience, and well-being while reducing resource intensity. Drawing on India's civilizational ethos and Mission Lifestyle for Environment (LiFE), the transition reimagines what it means to deliver growth, not through ever-rising energy, materials, and emissions, but through efficiency, smart design, and expanded opportunities for people. The challenge now is not conceptual but executional; building the enabling systems that allow each sector to move at scale and speed.

India can prioritize building this modern infrastructure under explicit carbon constraints, limited land and water availability, rising climate risks, rapid technological change, and shifting global trade rules. Compressing a century-long low-carbon transition done by others into a few decades creates economy-wide challenges that interact with sector-specific challenges.

Key system constraints include high cost of capital and thin project pipelines, state capacity gaps, and land, water, and network bottlenecks across grid, waste, and digital systems. Global headwinds including supply-chain concentration, geopolitical fragmentation, and emerging compliance regimes such as Carbon Border Adjustment Mechanism (CBAM) and European Union Regulation on Deforestation-free products (EUDR) add further pressure. At the same time, manufacturing depth, recycling systems, technology scale-up, and credible Measurement, Reporting, and Verification (MRV) frameworks can be strengthened to keep pace with demand. Affordability, equity, skills, and just transition concerns highlight the need for policies that protect vulnerable households, workers, and regions while enabling rapid sectoral change.

The Net Zero roadmap highlights key system shifts required to make that possible.

1. **Demand-side action is as important as clean supply:** The Mission LiFE approach coupled with an Avoid–Shift–Improve approach across transport, buildings, and industry is central to India's development and energy transition strategy:

    i. Reduce travel and wasteful consumption through compact cities, digitisation, and behavioural change.

    ii. Shift to public and mass transit systems, and non-motorised mobility.

    iii. Increase adoption of efficient appliances, optimizing industrial processes and making buildings (existing/new) Net Zero compliant.

Most demand side interventions have a low or even negative marginal costs of abatement. Their adoption eases infrastructure pressures, and accelerates emissions cuts.

2. **Demand electrification needs to be scaled by three times** to enable transition to Net Zero. End-use electrification across sectors such as mobility, cooking and heating, and industrial processes not only cuts carbon emissions but also boosts efficiency, and air quality.

3. **Power sector transformation is crucial.** We must build a renewables-dominated, reliable grid with significant baseload from nuclear power and adequate deployment of storage technologies by 2070. Strengthening grid infrastructure, and Distribution Company (DISCOM) reforms are important to ensure a smooth transition without compromising on reliability and affordability.

4. **Mission-mode implementation accelerates change.** Past national missions (Swachh Bharat, Pradhan Mantri Jan Dhan Yojana, Pradhan Mantri Kisan Samman Nidhi, Ayushman Bharat – Pradhan Mantri Jan Arogya Yojana) show that India performs best when institutions, targets, and funding are aligned. Similar, mission-mode programmes for sustainable mobility, industrial innovation, circular economy, clean cities, and electrification can deliver results at speed.

5. **Finance is the engine of the transition.** India must mobilise green investments of USD 150 – 200 billion per annum over the next ten years and scale up to USD 400–500 billion per year by mid-century. Achieving this requires lowering the cost of capital, blended finance and guarantees for early-stage technologies. In addition, deepening domestic capital markets, a strong climate taxonomy, and purpose-built institutions for green finance.

6. **Domestic manufacturing and supply chain resilience are strategic necessities:** Scaling up solar, batteries, EVs, green hydrogen, electrolysers, and storage at Indian volumes demands local manufacturing depth and supply-chain security. India must secure critical minerals through domestic exploration, recycling, and diversified global partnerships, while scaling manufacturing through incentives and ease of doing business. A green economy must also be a "Make in India" economy resilient to global risks.

7. **Innovation and digitisation are force multipliers for the transition.** Scaling-up India's Net Zero pathway and maintaining global competitiveness will require stronger R&D, faster piloting, and rapid scaling of frontier technologies such as green hydrogen, H_2-Direct Reduced Iron (DRI), Limestone Calcined Clay Cement (LC3), inert anodes, Carbon Capture Utilisation and Storage (CCUS), low-carbon materials, and advanced storage. At the same time, digital tools such as smart meters, intelligent transport systems, Internet of Things (IoT)-enabled grids, and interoperable platforms like the Unified Energy Interface (UEI) can boost efficiency, transparency, and system management. Together, technology and digitalisation accelerate adoption, reduce costs, and enhance the credibility of India's industrial transition.

8. **An inclusive, and affordable transition ensures public support.** Workers in fossil fuel linked sectors, low-income households, and resource-dependent regions must be protected, while land and water use must be managed to avoid conflict and safeguard livelihoods. A just and inclusive transition will require reskilling and redeploying affected workers while expanding opportunities in emerging green sectors, diversifying fossil fuel belt and other resource-dependent economies, protecting low-income households through periods of price and

income adjustment. It will require managing land and water pressures via spatial planning, basin-aware water strategies and prioritisation of degraded land, alongside promoting dual-use models such as agrivoltaics so that clean infrastructure can expand without displacing communities.

9. **Strengthen institutions and governance for whole-of-economy delivery.** India's Net Zero transition depends on coordinated action by line ministries and by State governments. This requires reinforcing existing coordination mechanisms such as the Prime Minister's Council on Climate Change through a permanent secretariat in the form of a Low-Carbon Development Cell/ Secretariat. Such an institution can align Central and State budgets with National Determined Contributions (NDC) cycles and ensure that sectoral and regional development plans remain consistent with India's climate commitments.

The Key Message

India can achieve the Viksit Bharat goal and Net Zero, but only if these system shifts are built effectively and early. This chapter consolidates insights from numerous sectoral and thematic working group reports into a single, decision-oriented narrative, discussing:

i. The cross-cutting enablers that unlock them (finance, resources-minerals, land and water, data, innovation, governance), and

ii. The delivery architecture needed to execute at scale.

Together, they define the enabling environment for a developed, modern, competitive, and inclusive Net Zero Bharat which is also Viksit Bharat. `

10.1 REFRAMING DEVELOPMENT FOR SUSTAINABLE GROWTH: LEVERAGING INDIA'S CIVILISATIONAL ETHOS AND MISSION LIFE

India's development trajectory is unfolding at a moment when economic growth consumption paradigm is in question:

The historical association between economic growth and rising resource consumption is increasingly being questioned. The dominant global model of development, shaped by the experience of industrialised economies, has been characterised by material-intensive growth, expanding energy demand, and a steady enlargement of ecological footprints. While this pathway delivered rapid economic expansion, it has also generated structural vulnerabilities in the form of climate instability, resource depletion, and heightened exposure to external shocks. For a country of India's scale and diversity, replicating such a trajectory in its conventional form would impose constraints not only on environmental sustainability but also on long-term economic resilience and social equity.

India's development challenge is therefore not limited to accelerating growth, but extends to redefining the quality, composition, and resource intensity of that growth. The central question is how development can be structured to deliver rising living standards while remaining consistent with ecological goals and national priorities for energy security, fiscal stability, and social inclusion. In this context, climate action emerges not as a peripheral obligation, but as an organising principle for a more efficient, resilient, and self-reliant growth model, anchored in lower exposure to commodity volatility and external shocks.

International experience already illustrates that high levels of human well-being are not mechanically correlated with high levels of material consumption. Japan, with a GDP per capita lower than that of the United States, records higher life expectancy, while Costa Rica achieves comparable health outcomes at a fraction of the income level, reflecting the importance of social systems, preventive healthcare, and active lifestyles over material intensity alone. These patterns underscore the scope for development pathways that prioritise efficiency, accessibility, and resilience over sheer volume of consumption. For India, this opens strategic space to pursue prosperity without replicating the most resource-intensive phases of industrialised growth.

An Indian Development Model

Together, these insights allow India to articulate an alternative development approach grounded in efficiency, sufficiency, and resilience. Several features of Indian living patterns already align with such a pathway. Traditional housing based on local materials, natural ventilation, and passive cooling entails far lower energy demand than globally prevalent glass-and-steel designs reliant on mechanical climate control. Multi-generational households, long characteristic of Indian society, reduce per capita energy and material use, particularly in dense urban environments. These embedded practices illustrate that lower-resource development pathways are socially viable and culturally anchored.

Suggestions:

i. **At the level of policy design, a coherent demand-side framework building on MIssion LiFE can be organised** around an economy-wide Avoid–Shift–Improve approach spanning transport, buildings, and industry. This encompasses the diffusion of super-efficient appliances and equipment, large-scale industrial retrofits, particularly among micro, small and medium enterprises, and the integration of circular material flows through recycled-content standards and extended producer responsibility. The systematic incorporation of behavioural dimensions, exemplified by Mission LiFE, extends the scope of demand-side action beyond technology into everyday consumption choices.

ii. **Energy efficiency occupies a central position** within this transition. Cooling demand alone is projected to rise sharply with improving living standards, potentially tripling in the coming decades. However, widespread deployment of high-efficiency appliances and building designs rooted in passive cooling could moderate this growth substantially. Across sectors, such measures are associated with a steady decline in India's energy intensity of GDP, supporting the decoupling of economic growth from energy consumption while preserving quality of life. This implies a gradual reorientation of developmental norms away from energy-intensive practices toward climate-responsive design and the use of local resources.

iii. **Behavioural change forms a complementary design dimension** of this transformation. Initiatives such as Mission LiFE provide a platform to normalise low-impact consumption patterns at scale, including moderation in cooling practices, shifts away from single-use plastics, rainwater harvesting, greater reliance on public transport, wider adoption of clean cooking fuels, and transitions toward sustainable agricultural practices.

Individually modest, such shifts acquire macroeconomic significance when embedded across households and communities.

iv. **Circularity further reinforces the demand-side transition** by lowering the material intensity of growth. Reduced reliance on virgin steel and cement, enhanced recycling of critical minerals, and longer product lifecycles contribute simultaneously to emissions reduction, import substitution, and resource security. In this sense, the circular economy operates not only as an environmental strategy but also as an instrument of industrial competitiveness and macroeconomic stability, particularly in a context of rising global material and supply-chain uncertainty.

Taken together, demand-side measures reduce future infrastructure requirements, ease pressure on land and mineral resources, and improve the affordability of the energy transition. By aligning development with efficiency, sufficiency, and cultural continuity, India's climate strategy gains robustness against external shocks and fiscal constraints, while preserving space for rising living standards. This integrated approach positions demand management not as a residual element of climate policy, but as a structural determinant of the pace, cost, and resilience of India's transition to Net Zero.

10.2 FINANCING INDIA'S NET ZERO TRANSITION: MOBILISING CAPITAL THROUGH SYSTEMIC FINANCIAL REFORM

India's development and low-carbon transition will require large volumes of long-tenor finance. Cumulative needs are USD 8 trillion by 2050 and USD 22.7 trillion by 2070, translating to USD 500 billion per year. These magnitudes align with other assessments-UBS estimates ~USD 19.6 trillion to 2070 and McKinsey ~USD 7.2 trillion to 2050.

Actual flows are far lower. The International Energy Agency (IEA) estimates finance flows of ~USD 135 billion in 2024 for India's energy system against the USD 500 billion annual requirement. Power accounts for nearly half of total needs as electricity's share in final energy demand is projected to rise from ~20% to ~60% by 2070.

The challenge is not only the quantum of capital, but the system's ability to channel diverse pools into investable, risk-adjusted opportunities. Banks/NBFCs face asset–liability mismatches, institutional investors are constrained by regulatory caps, corporate bond markets remain shallow, and high-risk premia (especially for newer technologies) deter foreign participation. Financing constraints are therefore structural, not merely volumetric.

A calibrated expansion of long-term foreign capital, particularly from sovereign wealth funds and global pension investors, can ease pressure on domestic savings, and lower borrowing costs. It helps to improve the macroeconomic feasibility of sustained high investment, even if accompanied by a modestly higher current account deficit relative to predominantly domestic-financed scenarios.

Suggestions:

i. **India's climate-finance agenda is organised under six priority pillars:** building a credible climate-finance data backbone, aligning regulatory frameworks with a unified Climate Finance Taxonomy (being developed by Dept of Economic Affairs, Government of India), closing the financing gap through reforms aimed at expanding private capital and attracting long-tenor foreign capital, accelerating project preparation and bankability, blending and sharing risk across stages and technologies and scaling credible transition finance to bridge brown-to-green pathways.

ii. **A structurally deeper corporate bond market is central** to providing long-tenor, non-bank financing for the transition, reducing reliance on bank balance sheets and improving risk distribution across the financial system.

iii. **Reorienting long-term institutional portfolios and household savings** towards green and transition assets expands the investible capital base while embedding climate finance within India's broader development finance architecture.

iv. **A National Green Finance Institution (NGFI):** It is envisaged that a purpose-built institutional mechanism in form of NGFI can crowd in private capital, de-risk emerging technologies, and coordinate fragmented financial actors.

Institutions such as International Financial Services Centre Authority (IFSCA)/Gujarat International Finance Tech (GIFT) City can complement this architecture by serving as systemic co-investment hubs, reducing regulatory friction, foreign exchange hedging costs, and documentation asymmetries for global capital seeking exposure to taxonomy-aligned green assets.

The core objectives of the proposed NGFI include:

- **Scale bankable sectors** through refinancing windows, aggregation platforms, and green credit lines.
- **De-risk emerging technologies** using guarantees and VGF with sunset clauses until commercial viability is achieved**.**
- **Channel blended capital** to crowd in private and foreign investors at lower premia.

A dedicated white paper developed through structured consultation with regulators, financial institutions, industry, and investors should set out the NGFI's mandate, governance, eligible instruments, risk framework, and capitalization plan.

10.3 DOMESTIC MANUFACTURING AND SUPPLY-CHAIN RESILIENCE IN INDIA'S NET ZERO TRANSITION

India's Net Zero transition coincides with a decisive phase in its structural transformation. Manufacturing's share of GDP stands at around 18 % with scope to grow further. Over the past decade, policy emphasis has therefore shifted towards rapid manufacturing growth and infrastructure-led expansion, reflected in initiatives such as the Production-Linked Incentive schemes and the National Manufacturing Mission across electronics, pharmaceuticals, automotive, textiles, semiconductors, and clean energy technologies. This direction aligns with the longer-term objective of absorbing surplus rural labour, raising productivity, diversifying exports, and moving up global value chains.

The Net Zero transition adds a new strategic dimension to this industrial agenda. Scaling solar, batteries, electric vehicles, electrolysers, green hydrogen, and energy storage at Indian volumes implies sharply higher demand for critical minerals, components, and advanced manufacturing. The central opportunity lies in translating this deployment demand into domestic production depth, thereby strengthening energy security, reducing external vulnerabilities, and accelerating learning-by-doing in clean technologies. Domestic manufacturing depth and supply-chain resilience thus become not only an industrial priority but a key enabler of a cost-effective and timely Net Zero pathway.

India's manufacturing trajectory will also be shaped by evolving global production dynamics. Manufacturing worldwide has become increasingly capital-intensive, as rapid advances in automation, digital technologies, and artificial intelligence are reshaping traditional pathways of industrialisation. In this context, competitiveness depends less on scale alone and more on focused specialisation, faster productivity growth, and the ability to integrate low-carbon production as a source of value rather than as a compliance obligation.

At the domestic level, this global shift intersects with existing structural features of Indian manufacturing. Domestic production remains dependent on imports for several critical components and sub-systems, particularly in appliances, power electronics, and clean energy technologies. This dependence extends beyond raw materials to include precision components, specialised machinery, and certain process technologies, shaping both cost structures and vulnerability to external disruptions. At the same time, limited availability of verified product-level emissions data and embodied-carbon benchmarks constrains the capacity of markets to distinguish cleaner products from conventional alternatives, weakening incentives for low-carbon manufacturing differentiation.

Circular economy pathways are closely linked to the scale and structure of domestic manufacturing. At current manufacturing levels, material recovery from recycling is expected to contribute to meeting a portion of domestic demand for selected battery and clean-tech minerals. As manufacturing depth expands, the balance between secondary material recovery and primary resource use is likely to evolve, reflecting the interaction between industrial scale, technology choices, and global material flows.

Suggestions:

A manufacturing strategy aligned with India's Net Zero transition can be organised around three reinforcing objectives: building domestic production depth, strengthening supply-chain resilience, and embedding low-carbon competitiveness as a structural advantage.

i. **Reorient industrial incentives towards building complete clean-technology value chains** rather than only final assembly. The PLI framework can be leveraged across clean energy equipment, appliances, and advanced materials, with stronger MSME participation and closer alignment between industrial policy and mission-oriented R&D to move technologies from pilot scale to commercial manufacturing.

ii. **Strengthen supply-chain resilience through a coordinated minerals-to-manufacturing approach.** Stronger domestic exploration and geological data expanded refining and advanced recycling capacity and diversified overseas mineral partnerships together improve the reliability of material and intermediate inputs for clean manufacturing.

iii. **Embed low-carbon production as a source of industrial competitiveness** through clear embodied-carbon benchmarks and lifecycle-based public procurement. Promote trade policy that eases access to essential intermediate inputs and equipment for green value chains to reinforce cost competitiveness and support domestic capability in clean manufacturing.

10.4 BUILDING A COHERENT AND TRUSTED ENERGY DATA ARCHITECTURE

India's Net Zero execution hinges on trusted, interoperable data. Today, however, the energy-data landscape is fragmented across producers, consumers, fuels, and agencies, slowing decision-making, and raising transaction costs.

The first challenge is non-uniform classifications and methods. End-use categories and product definitions vary across ministries and often diverge from ISIC (International Standard Industrial Classification of all Economic Activities) and SIEC (Standard International Energy-product Classification). For example, the Central Electricity Authority (CEA) reports Industry as a single consolidated consumer for coal consumption, while the Ministry of Coal reports granular sub-sectors (steel, cement, etc.). Coal classifications used by the Ministry of Coal are also not aligned with international standards. Further, conversion factors are not consistently harmonised. These divergences constrain the assembly of a coherent national energy balance and complicate comparison with international series.

The second challenge is specific gaps and "black boxes." Examples include: a large "Others" bucket in industrial coal use reported by the coal ministry; no sectoral end-use view for imported coal; HSD volumes concentrated under the "Retail/Reseller" category in Ministry of Petroleum and Natural Gas (MoPNG) reporting, masking true end-users; bioenergy flows are not tracked by any single ministry; and international marine/aviation bunkers not included in Total Primary Energy Supply (TPES).

The third challenge is cross-source inconsistency and incomplete external reporting. Headline indicators (e.g., per-capita electricity consumption) and average coal GCV to power differ between Ministry of Statistics and Programme Implementation (MoSPI) and CEA. Together, these gaps limit the analytical completeness of India's energy system view.

Finally, digitisation is uneven across sectors and user-facing systems. Interoperability for EV charging remains limited, constraining seamless discovery and payments across charging networks and missing a chance to create continuous, user-level demand signals. Unified Energy Interface (UEI) is conceived in India to address the challenge of seamless discovery and settlement, a UPI-like, open network for energy transactions built on the Beckn protocol (Beckn Protocol is an open and interoperable protocol for decentralised digital commerce), starting with EV-charging interoperability, and advanced by the UEI Alliance alongside the government's emerging India Energy Stack vision from the Ministry of Power.

Suggestions:

i. **Bridge national energy-statistics gaps:** The newly formed MoSPI Expert Committee should design a time-bound plan to reconcile classifications with ISIC/SIEC, standardise conversion factors, and resolve gaps that exist in the current energy statistics.

ii. **Align national series and climate reporting**: MoSPI's energy series can be aligned with MoEFCC's Biennial Transparency Report (BTR) pathway from Tier-1 to Tier-3, ensuring consistency between emissions inventories and energy balances. Disclosure frameworks can be aligned with the Climate Finance Taxonomy (under development) and SEBI's Business Responsibility and Sustainability Reporting (BRSR)/BRSR-Core.

The national dashboard (ICED) can be strengthened as the single source of truth, with versioned methodologies and transparent reconciliation notes.

iii. **Strengthen state-level energy and emissions statistics:** Establish state cells to produce annual energy balances and GHG inventories consistent with national methods (moving towards BTR Tier-3 granularity). Provide a common template, conformance checks, and an ICED-State workspace that rolls up to the national view while preserving state-level metadata and audit trails.

iv. **Recognize Unified Energy Interface (UEI) for EVs as the first digital rail (and beyond):** UEI can serve as the interoperability layer for EV charging, with UEI-readiness integrated into publicly supported and fleet chargers. By enabling seamless discovery, payments, and settlement across networks, UEI lowers transaction costs, supports roaming and demand response, and provides the transactional foundation for the India Energy Stack, while generating high-quality system-level data for national and state planning.

10.5 INNOVATION AND RESEARCH & DEVELOPMENT: BUILDING INDIA'S LOW-CARBON TECHNOLOGY FRONTIER

India's Net Zero pathway depends both on scaling existing low-carbon solutions and advancing the technological frontier in hard-to-abate sectors. The national R&D effort needs to be stepped up from the current levels to take advantage of the opportunity. Innovation activity today remains concentrated in pharmaceuticals, IT, transport, defence, and biotechnology, while climate-relevant domains receive less attention. R&D output mirrors this pattern. India generated around 2,800 environment-related patents in the past decade, roughly one-tenth of China or Germany. These need to improve for India to shape, rather than follow, global low-carbon value chains.

The structural implications are significant. Nearly half of global emissions reductions required by mid-century depend on technologies that remain at prototype or demonstration stage, including green hydrogen and ammonia, carbon capture and storage, long-duration energy storage, low-carbon steel and cement, and advanced biofuels and sustainable aviation fuels.

A thin domestic pipeline in these areas risks locking India into technology import dependence at higher long-term cost. Further, private sector participation in climate-relevant R&D remains limited and concentrated, while start-ups and MSMEs face capital and risk barriers that restrict commercialisation and patenting. The persistence of the "valley of death", driven by weak early-stage demand and limited green procurement, further slows the transition from laboratory to market.

Suggestions:

i. **Expand total R&D with a larger role for business expenditure.** This will align India more closely with innovation-driven growth pathways. Raising business shares of R&D personnel and researchers towards top-ten-economy benchmarks would deepen industry-embedded innovation capacity, while sectoral low-carbon innovation funds with milestone-linked support such as electrolyser cost trajectories and battery energy-density benchmarks can improve capital allocation toward climate-relevant technologies.

ii. **Establish Mission-oriented clusters** that pool CSIR, IITs, IISc, national laboratories, and industry with explicit technology-to-commercialisation pathways across hydrogen and ammonia, CCUS, long-duration storage, green steel and cement, and advanced biofuels and SAF. This will reduce fragmentation and accelerate learning curves. Clean-tech innovation hubs and incubators, equipped with shared laboratories and pilot-scale facilities such as battery centres and high-voltage testing, can co-locate researchers, start-ups, and industry, while mobilising CSR and impact capital to bridge early-stage risk.

iii. **Market creation remains critical to overcoming the innovation–deployment gap.** Targeted mandates such as partial green hydrogen use in fertilisers and public procurement of green steel and cement can seed early demand and de-risk first movers. Regulatory sandboxes for vehicle-to-grid integration, peer-to-peer trading, and carbon-capture utilisation pilots, alongside the development of technical standards for hydrogen quality, battery safety, and system interoperability, can further build investor and consumer confidence.

iv. **India's innovation system stands to benefit from deeper integration into global knowledge networks.** Mission-oriented alliances and bilateral programmes, selective licensing and joint ventures, and expanded fellowships and research exchanges can embed frontier expertise in Indian institutions while preserving domestic technological depth.

10.6 GOVERNANCE, REGULATION AND INSTITUTIONS: ALIGNING ACCOUNTABILITY

India's Net Zero transition spans ministries, sectors, and multiple tiers of government, embedding climate action within a complex institutional landscape. Existing arrangements comprising the Prime Minister's Council on Climate Change (PMCCC), the Ministry of Environment, Forest and Climate Change (MoEFCC), line ministries, regulators, and state agencies have enabled substantial progress. However, coordination and follow-through can improve. Climate action continues to be pursued largely through sectoral instruments rather than through an integrated legal or institutional framework.

The division of responsibilities complicates execution. While electricity lies in the concurrent list, land, water, agriculture, and urban governance are largely state subjects, creating a persistent misalignment between central policy direction and state-level delivery capacity.

At the delivery level, low-carbon growth levers are distributed across jurisdictions with significant variation in capacity, data systems, and fiscal incentives across states. Although State Action Plans on Climate Change (SAPCCs) exist, their integration with state budgets, sectoral plans, and investment pipelines remains uneven, raising transaction costs and contributing to fragmented execution.

In parallel, regulatory frameworks have not consistently evolved to reward flexibility or low-carbon choices. Core rules and administrative codes covering power markets, permissions, urban planning, labour, and dispute resolution often rely on case-by-case clearances. These features elevate risk premia, delay otherwise bankable investments, and inflate system costs.

Institutional capacity continues to constrain the pace and consistency of delivery. Execution agencies including DISCOMs, State Pollution Control Boards (SPCBs), State Electricity Regulatory Commissions (SERCs), Urban Local Bodies (ULBs), and line departments operate under significant human, technical, and analytical constraints, limiting the effectiveness of policy intent on the ground.

Suggestions:

i. **Strengthening apex coordination and strategic coherence.** Strengthen the Prime Minister Council on Climate Change as the apex coordination forum to anchor institutional reform.

   - Establish a full-time Low-Carbon Development Cell/Secretariat to professionalise climate governance by providing analytics, coordinating cross-cutting bottlenecks such as land, transmission, and finance, and issuing implementation guidance that aligns missions and schemes across ministries.
   - Embed the National Determined Contributions (NDC) cycle into domestic planning through sectoral and state-level five-year roadmaps and development plans, to translate international commitments into sustained domestic accountability. Independent assessment mechanisms, anchored in DMEO and NITI Aayog through an Annual Climate Progress Report, can strengthen transparency and evidence-based course correction.

ii. **Improving centre–state alignment and delivery systems.** Provide pooled technical assistance for states, alongside embedded climate cells in key departments supported by shared analytics from the Low Carbon Development Cell/Secretariat, to reduce transaction costs and improve execution quality.

iii. **Modernising regulatory processes (software) to lower risk and accelerate deployment**

   - **Align electricity market design, tariffs, and grid codes** to support storage, demand response, open access, and predictable curtailment compensation can reduce system costs and risk premia.
   - **Standardise digital, time-bound land and environmental clearances** and clarifying low-risk dual-use land categories, such as agrivoltaics, can accelerate project timelines without diluting safeguards.
   - **Integrate energy codes into urban permits,** digitising approvals aligned with national model codes, and operationalising risk-based labour safeguards consistent with safety and efficiency norms can further reduce regulatory friction.
   - **Undertake complementary reforms in compliance, inspection, and dispute resolution** through risk-based inspections, integrated single-window interfaces, fast-track climate-relevant disputes, and pre-announced performance standards with defined transition pathways can enhance regulatory certainty and lower the cost of capital.

iv. **Build institutional capacity for sustained delivery**. Strengthen institutional capacity through training, shared analytics and Monitoring Reporting and Verification (MRV) frameworks, and improved staffing of climate cells at all levels to support sustained and effective climate governance.

10.7 MAPPING VULNERABILITY, COSTING RESILIENCE

Adaptation constitutes a first-order development priority and an unavoidable addition to development costs. It is neither a co-benefit of mitigation nor a substitute for it. Climate-resilient development entails real trade-offs, with uneven burdens across regions and communities. IPCC AR6 underscores that opportunities for climate-resilient development diminish with rising warming, and that equity and capability shape how countries balance adaptation and mitigation. These realities frame adaptation not merely as an environmental concern but as a core determinant of development outcomes.

India faces significant exposure across its coasts, the Himalayan region, water-stressed basins, and rapidly urbanising districts. Rising climate risks are already imposing mounting costs on infrastructure, livelihoods, and public finances, elevating resilience from a sectoral issue to a macroeconomic imperative. Yet the spatial distribution of risk, the heterogeneity of impacts across sectors, and the absence of uniform vulnerability baselines complicate prioritisation and resource allocation.

The scale of the challenge is substantial. India's Initial Adaptation Communication estimates INR 56.68 trillion for adaptation to 2030 under business-as-usual, with potential climate damage costs of INR 15.5 trillion by 2030 and total pressures approaching INR 72 trillion when development and climate stresses are jointly accounted for. At the same time, global climate finance has consistently fallen short of pledges, with adaptation receiving a modest share relative to need. This reinforces India's reliance on domestic resources even as the case for scaled, predictable, and concessional international support remains strong.

Even with effective adaptation, residual impacts and loss and damage will occur when hazards exceed coping capacity. Anticipating and planning for such outcomes is therefore an integral part of a realistic resilience strategy rather than a marginal consideration.

Suggestions:

i. **Strengthening knowledge systems and anticipatory capacity.** Enhance high-resolution climate modelling, expand observation networks, and develop bottom-up risk profiling across sectors and regions. Strengthen climate services and last-mile communication to translate risk information into actionable insights for communities, planners, and investors.

ii. **Reducing exposure through spatial and infrastructure planning:** Expand the reach and reliability of early warning systems; upgrade urban stormwater and drainage systems; improve river, coastal, and watershed risk management; protect and restore ecosystem buffers; and embed long-horizon land-use choices into urban and regional planning frameworks.

iii. **Building adaptive capacity and resilience at scale:** Promote R&D and Make-in-India adaptation technologies; expand inclusive credit and social safety nets; support livelihood diversification; and strengthen gender-responsive and community-led approaches to resilience. A critical enabling step is a comprehensive national vulnerability and adaptation-costing exercise, designed to:

- Produce district- and asset-level vulnerability maps integrating hazards, exposure, and socio-economic sensitivity
- Establish uniform damage-and-loss baselines
- Estimate adaptation costs by sector and geography, including capital, O&M, and residual-risk buffers
- Aggregate results into a medium-term financing envelope distinguishing domestic resources from concessional and grant needs.

These outputs can directly inform standards and codes, land-use plans, and public investment appraisal, and establish a framework for tracking resilience outcomes over time.

Way Forward to Net Zero

India's Net Zero transition will ultimately be decided not by ambition but by delivery. The chapters show that low-carbon growth is a mosaic of many simultaneous moves: mobility that avoids–shifts–improves; industries that double down on efficiency, electrification, circularity, and frontier technologies; buildings that embed Net Zero-ready design and enforce it; a power system rebuilt for scale, stability, and speed; and agriculture that aligns mitigation with income, water security, and resilience.

However, to ensure these ambitions materialize, India needs a purpose-built delivery architecture: one that turns policy into bankable pipelines, connects capital to results, and ensures accountability and agility at every step. Framed as a triangular model (Figure 10.1), the proposed architecture has three integral layers:

i. **At the apex, High-Level Climate Governance and Coordination:** Strategic direction must come from an empowered apex body—such as a reconstituted Low Carbon Development Cell/ Secretariat tasked with inter-ministerial coordination, long-term planning, and alignment of national, state, and sectoral targets. Five-year emissions and investment budgets, linked to the NDC cycle, can provide continuity and accountability.

ii. **At the core, Mobilising Finance through Institutional Mechanisms:** Finance is the bridge between policy and execution. A dedicated National Green Finance Institution, along with standardised project pipelines (e.g. ASSET), a green taxonomy, blended finance structures, and risk-sharing tools, will be essential to crowd in private and foreign capital without displacing domestic priorities.

iii. **At the base, Implementation through Enabling Pillars:**
    - Regulatory and Market Reforms: Reforms are needed to unlock private investment, ensure cost-reflective pricing, streamline clearances, and strengthen institutions such as SERCs, DISCOMs, ULBs, and financial regulators.
    - Mission-Mode Implementation and Innovation: Time-bound national missions with empowered secretariats, digital Monitoring, Reporting, and Verification (MRV), and access to finance can drive large-scale transformation in priority areas.

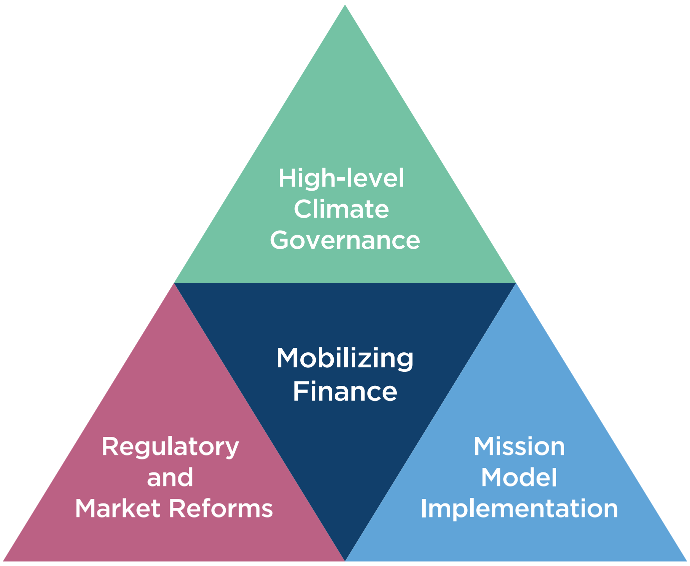


Figure 10.1: Delivery architecture for Net Zero

A few principles tie this agenda together:

i. **Sector-specific, solution-stacked action:** Passenger and freight systems must rebalance toward mass transit, rail and waterways, and EVs, while improving safety and logistics performance. Industrial low-carbon growth demands MSME-centred efficiency and electrification now, while India pilots H_2-DRI, LC3, inert anodes, and CCUS to bend future cost curves. Buildings policy must expand beyond design-stage operational energy to whole-life performance, retrofits, and commissioning. Power must add clean baseload, storage, and RE hybrids while modernizing coal operations. Agriculture must sequence crop diversification, water-smart rice, nutrient balance, and livestock productivity so climate gains flow through income and resilience.

ii. **Supply-chain and resource realism**: Critical minerals, domestic manufacturing, and circularity must advance together so clean systems do not replicate fossil-era dependencies. Land and water constraints demand low-conflict siting, dual-use models such as agrivoltaics and floating solar), and basin-aware planning.

iii. **Data, digital rails, and standards as the trust fabric:** Harmonised classifications, open dashboards, stronger MRV, and interoperable rails like the Unified Energy Interface move markets from claims to verifiable performance and lower transaction costs across EVs, energy services, and finance.

iv. **People-first transitions:** Skilling, redeployment, inclusion, and affordability will determine the pace of India's transition. Mapping exposed workers and communities, sequencing retrain-to-retain pathways, steering green investment toward vulnerable districts, and cushioning near-term price effects with targeted transfers and mass-market efficiency are essential.

Mission-Mode Implementation and Innovation

Four national missions can focus effort, funding, and innovation on cross-sector outcomes, each backed by small empowered secretariats, time-bound targets, digital MRV, and access to finance:

i. **Mission on Demand-Side Management**—super-efficient appliances, digital building -code enforcement, city programmes for shared mobility and non-motorised transport aligned with Mission LiFE.

ii. **Mission on Circular Economy**—EPR-anchored recycled-content targets, industrial symbiosis under clear standards, formalised last-mile collection, organised scrap markets with digital material-flow tracking, and fiscal levers to reduce virgin-material dependence.

iii. **Mission on Systemic Electrification**—electrification of transport, buildings and industry with clean power: ZEV mandates, EV-ready codes, interoperable charging (UEI), process-temperature maps, concessional support for electric boilers/furnaces/heat pumps, scaled captive/RESCO models and streamlined open access.

iv. **Mission on Industrial Innovation**—pilot-to-demo programmes for H_2-DRI, LC3, inert anodes and CCUS, green-hydrogen hubs that co-locate renewables/electrolysers/ offtakers, buyers' platforms and green public procurement, and domestic manufacturing with clear standards, taxonomy and product-carbon certification.

If India executes such a programme with discipline—sector stacks plus enabling stacks, finance plus institutions, technology plus people—it can deliver a credible emissions pathway to Net Zero while strengthening competitiveness, resilience, and inclusion. The outcome will not only be a lower-carbon economy, but a better-built Viksit Bharat**:** cleaner air and safer streets, efficient, future-ready industries and buildings, a reliable, digital, and flexible grid, resilient farms and livelihoods, and institutions capable of delivering at the scale and speed demanded by a Viksit Bharat.

The transition is India's opportunity to shape a Viksit Bharat—cleaner, more competitive, and more resilient.

REFERENCES

References

1. Acheampong, A. O., Erdiaw-Kwasie, M. O., & Abunyewah, M. (2021). Does energy accessibility improve human development? Evidence from energy-poor regions. *Energy Economics, 96*, 105165. https://doi.org/10.1016/j.eneco.2021.105165

2. Basu, R., Banerjee, T., & Roy, S. (2022). Impact of climate change on water availability, food insecurity, and malnutrition in India: A systematic review. Food Policy, 103, https://www.sciencedirect.com/science/article/pii/S266604902500009X

3. Bhushan, C. and Banerjee, S. 2021. Five R's: A Cross-sectoral landscape of Just Transition in India, International Forum for Environment, Sustainability and Technology (iFOREST), New Delhi

4. BP. (2016). *BP statistical review of world energy 2016* (65th ed.). BP plc. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/BP-statistical-review-of-world-energy-2016-full-report.pdf

5. Bureau of Energy Efficiency. (2023). *Impact assessment 2022–23*. Ministry of Power, Government of India. https://beeindia.gov.in/sites/default/files/publications/files/Impact%20Assessment%202022-23_%20FINAL%20Report.pdf

6. BP. (2016). *BP statistical review of world energy 2016* [Report]. BP p.l.c. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/BP-statistical-review-of-world-energy-2016-full-report.pdf

7. CEEW and UNICEF. 2025. How Can India Make its Health Sector Climate Resilient? A District-level Risk Assessment. New Delhi, India: Council on Energy, Environment and Water. https://www.ceew.in/sites/default/files/ceewhow-can-india-make-its-health-sector-climate-resilient20mar25-for-web.pdf

8. Central Ground Water Board. (2025). National compilation on Dynamic Groundwater resources of India https://cgwb.gov.in/cgwbpnm/download/1741#page=171

9. Central Pollution Control Board. (2025). *Polluted river stretches for restoration of water quality – 2025*. Ministry of Environment, Forest and Climate Change, Government of India. https://nmcg.nic.in/pdf/POLLUTED%20RIVER%20STRETCHES%20FOR%20RESTORATION%20OF%20WATER%20QUALITY.pdf

10. Central Electricity Authority. (n.d.). *CDM – CO baseline database for the Indian power sector* [Online database]. Government of India. https://cea.nic.in/cdm-co2-baseline-database/?lang=en

11. Central Electricity Authority. (2025, March 31). *All India installed capacity (allocation-wise) of power stations as on 31.03.2025* [Statistical report]. Government of India. https://cea.nic.in/wp-content/uploads/installed/2025/03/IC_March_2025_allocation_wise.pdf

12. Climate Policy Initiative (CPI). (2025). *Global landscape of climate finance 2025*. https://www.climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2025/

13. Climate Policy Initiative (CPI). (2023). *Global landscape of climate finance 2023*. https://www.climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2023/

14. Climate Policy Initiative (CPI). (2024a). *Global landscape of climate finance 2024: Insights for COP29* (Report). https://www.climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2024/

15. Climate Policy Initiative (CPI). (2024b). *Landscape of Green Finance in India 2024*. https://www.climatepolicyinitiative.org/publication/landscape-of-green-finance-in-india-2024/

16. Department of Land Resources & National Remote Sensing Centre. (2019). *Wastelands atlas of India 2019*. Ministry of Rural Development, Government of India. https://dolr.gov.in/wasteland-atlas-of-india-2019/

17. Department of Land Resources & National Remote Sensing Centre. (2019). *Wastelands atlas of India 2019*. Ministry of Rural Development, Government of India. https://dolr.gov.in/wasteland-atlas-of-india-2019/

18. Directorate of Economics and Statistics, Department of Agriculture & Farmers Welfare. (2024). *Land use statistics at a glance 2022-23*. https://desagri.gov.in/wp-content/uploads/2024/09/Final-file-of-LUS-2022-23-for-uploading.pdf

19. Energy Institute, KPMG, & Kearney. (2025). *Statistical review of world energy 2025*. Energy Institute. https://assets.kpmg.com/content/dam/kpmg/sk/pdf/2025/Statistical-Review-of-World-Energy-2025.pdf

20. Gaye, A. (2008). *Access to energy and human development* [Human Development Report research paper]. United Nations Development Programme. https://hdr.undp.org/content/access-energy-and-human-development

21. Genchi G, Carocci A, Lauria G, Sinicropi MS, Catalano A. Nickel: Human Health and Environmental Toxicology. Int J Environ Res Public Health. 2020 Jan 21;17(3):679. doi: 10.3390/ijerph17030679 PMCID: PMC7037090 PMID: 31973020

22. Goldar, A., Jain, S., & Dasgupta, D. (2024). Estimating loss and damage from climate-induced disasters: An Evaluation using ICRIER 'Prakriti' Model (Working Paper No. 422). Indian Council for Research on International Economic Relations (ICRIER). https://icrier.org/pdf/Working_Paper_422.pdf

23. Government of India. (2022, November). *India's long-term low-carbon development strategy (LT-LEDS)* [Strategy document]. United Nations Framework Convention on Climate Change. https://unfccc.int/sites/default/files/resource/India_LTLEDS.pdf

24. Greenmatch. (2024, July 15). Is lithium mining bad for the environment? https://www.greenmatch.co.uk/blog/is-lithium-mining-bad-for-the-environment

25. IDMC, Countdown to 2030: Achieving global targets on disaster displacement, June 2025. https://doi.org/10.55363/IDMC. BYHP3738

26. International Energy Agency. (2024). *World energy employment 2024*. https://iea.blob.core.windows.net/assets/a0432c97-14af-4fc7-b3bf-c409fb7e4ab8/WorldEnergyEmployment.pdf

27. Indian Institute of Management Ahmedabad. (2024). *Synchronising energy transitions toward possible Net Zero for India: Affordable and clean energy for all* – https://energyconsortium.iima.ac.in/wp-content/uploads/2024/11/Synchronising-Energy-Transitions-IIMA-Report-2024.pdf

28. International Energy Agency, International Renewable Energy Agency, United Nations Statistics Division, World Bank, & World Health Organization. (2024). *Tracking SDG 7: The energy progress report 2024* [Report]. World Bank. https://iea.blob.core.windows.net/assets/cdd62b11-664f-4a85-9eb6-7f577d317311/SDG7-Report2024-0611-V9-highresforweb.pdf

29. International Energy Agency. (n.d.). *Global energy crisis* [Topic page]. IEA. https://www.iea.org/topics/global-energy-crisis

30. International Energy Agency (IEA). (2025). *World energy investment 2025*. https://www.iea.org/reports/world-energy-investment-2025

31. International Energy Agency (IEA). (2024). *World Energy Investment 2024*. https://iea.blob.core.windows.net/assets/60fcd1dd-d112-469b-87de-20d39227df3d/WorldEnergyInvestment2024.pdf

32. International Monetary Fund. (2025). *India — country data profile: IMF DataMapper* [Data portal]. https://www.imf.org/external/datamapper/profile/IND

33. International Monetary Fund. (2025). *World Economic Outlook database, April 2025: GDP, current prices (NGDPD) for China and the United States* [Data set]. IMF. https://www.imf.org/external/datamapper/NGDPD@WEO/CHN/USA

34. KPMG. (2025). *Statistical review of world energy 2025* [Report]. KPMG. https://assets.kpmg.com/content/dam/kpmg/sk/pdf/2025/Statistical-Review-of-World-Energy-2025.pdf

35. Lancet Countdown on Health and Climate Change. (2024). *Lancet Countdown 2024: India policy priorities*. https://lancetcountdown.org/wp-content/uploads/2024/10/Lancet-Countdown-2024_India-Policy-Priorities.pdf

36. Madhusudan, M. D., & Vanak, A. T. (2023). Mapping the distribution and extent of India's semi-arid open natural ecosystems. Journal of Biogeography, 50(8), 1377–1389. https://doi.org/10.1111/jbi.14471

37. Ministry of Environment, Forest and Climate Change (MoEFCC). India: Third National Communication and Initial Adaptation Communication to the United Nations Framework Convention on Climate Change. New Delhi: Government of India; 2023.

38. Ministry of Jal Shakti, Press Information Bureau, Government of India. (2024, February 5). *Per capita water availability* [Press release] https://www.pib.gov.in/PressReleaseIframePage.aspx?PRID=2002726

39. Ministry of New & Renewable Energy. (2025). Renewable energy statistics 2024-25. Government of India. https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2025/11/202511061627678782.pdf

40. Ministry of Statistics and Programme Implementation. (2024). Annual report: Periodic Labour Force Survey (PLFS) 2023-24. https://www.mospi.gov.in/sites/default/files/publication_reports/AnnualReport_PLFS2023-24L2.pdf

41. Ministry of Finance. (2025). *Economic Survey 2024–25: Chapter 12 – Employment and skill development: Existential priorities*. Government of India. https://www.indiabudget.gov.in/economicsurvey/doc/eschapter/echap12.pdf

42. Ministry of Statistics and Programme Implementation. (2024, July 20). *Press release on Periodic Labour Force Survey (PLFS), 2023–24* (Press Release No. PRID=2085956). Government of India. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2085956

43. Ministry of Statistics and Programme Implementation. (2025, March 27). *Energy Statistics India 2025* [Report]. National Statistics Office, Government of India. https://www.mospi.gov.in/sites/default/files/publication_reports/Energy_Statistics_2025/Energy%20Statistics%20India%202025_27032025.pdf

44. Ministry of New & Renewable Energy. (2025, September 11). *Achieves over half of 2030 target of 500 GW: Union Minister Joshi reviews progress of renewable energy capacity addition* [Press release]. Press Information Bureau, Government of India. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2165645

45. Ministry of Environment, Forest and Climate Change. (2008). *National Action Plan on Climate Change* [Policy document]. Government of India. https://moef.gov.in/national-action-plan-on-climate-change

46. Ministry of Finance. (2023, February 1). *Budget 2023-24: Speech of Nirmala Sitharaman, Minister of Finance* [Budget speech]. Government of India. https://www.indiabudget.gov.in/doc/bspeech/bs2023_24.pdf

47. Ministry of Environment, Forest and Climate Change. (2024, December). *India: Fourth Biennial Update Report to the UNFCCC (BUR-4)* [National communication report]. United Nations Framework Convention on Climate Change. https://unfccc.int/sites/default/files/resource/India%20BUR-4.pdf

48. Ministry of Statistics and Programme Implementation. (2024, September 23). *Annual report, PLFS 2023-24: Periodic Labour Force Survey (July 2023–June 2024)* [Report]. National Sample Survey Office, Government of India. https://www.mospi.gov.in/sites/default/files/publication_reports/AnnualReport_PLFS2023-24L2.pdf

49. Ministry of Finance. (2025, February 1). *Budget 2025-26: Speech of Nirmala Sitharaman, Minister of Finance* [Budget speech]. Government of India. https://www.indiabudget.gov.in/doc/budget_speech.pdf

50. Ministry of Housing and Urban Affairs (MoHUA). (n.d.). *Metro Rail Sector* [Factsheet]. https://mohua.gov.in/upload/uploadfiles/files/Metro%20Rail%20_%20MoHUA.pdf

51. Ministry of Road Transport and Highways (MoRTH). (2024, December 15). *Year End Review 2024: Ministry of Road Transport and Highways* [Press release]. Press

Information Bureau, Government of India. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2091508

52. Ministry of Petroleum and Natural Gas. (2025, July 30). *Government takes multiple steps to safeguard citizens from impact of global oil price volatility* [Press release]. Press Information Bureau, Government of India. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2159407

53. Ministry of Statistics and Programme Implementation. (2025, March 27). *Energy Statistics India 2025* [Statistical report]. National Statistical Office, Government of India. https://mospi.gov.in/sites/default/files/publication_reports/Energy_Statistics_2025/Energy%20Statistics%20India%202025_27032025.pdf

54. Ministry of Statistics and Programme Implementation. (2025, March 27). *Energy Statistics India 2025* [Statistical report]. National Statistical Office, Government of India. https://mospi.gov.in/sites/default/files/publication_reports/Energy_Statistics_2025/Energy%20Statistics%20India%202025_27032025.pdf

55. MSSRF., (2024). How does climate change impact women and children across agro-ecological zones in India: A scoping study. M S Swaminathan Research Foundation. https://www.mssrf.org/sites/default/files/2025-05/Report-CCW-Study-v2-a_0.pdf

56. National Centre for Disease Control. (2024). Report of heat related activities conducted in India in 2024. Ministry of Health and Family Welfare. https://ncdc.mohfw.gov.in/wp-content/uploads/2024/12/Report-of-Heat-Related-Activities-2024_NPCCHH.pdf

57. NITI Aayog. (2019, August). *Composite water management index 2019* (in association with the Ministry of Jal Shakti and the Ministry of Rural Development) . NITI Aayog. https://www.niti.gov.in/sites/default/files/2023-03/CompositeWaterManagementIndex.pdf

58. NITI Aayog. (2023). *National Multidimensional Poverty Index: A progress review 2023* [Report]. Government of India. https://www.niti.gov.in/sites/default/files/2023-08/India-National-Multidimentional-Poverty-Index-2023.pdf

59. Organisation for Economic Co-operation and Development (OECD). (2024). *Climate finance provided and mobilised by developed countries in 2013–2022*. OECD Publishing. https://www.oecd.org/climate-change/finance-provided-and-mobilised-by-developed-countries/

60. Our World in Data. (2023). *Per-capita greenhouse gas emissions* [Dataset]. https://ourworldindata.org/grapher/per-capita-ghg-emissions

61. Pascale, A., Osiolo, H., Narayanan, G., & Kwon, O. (2022). Can transitioning to non-renewable modern energy decrease carbon dioxide emissions in India? *Energy Research & Social Science, 91*, 102733. https://doi.org/10.1016/j.erss.2022.102733

62. Pandey, A., Brauer, M., Cropper, M. L., et al. (2021). *Health and economic impact of air pollution in the states of India: The Global Burden of Disease Study 2019. The Lancet Planetary Health,* 5(1), e25–e38. https://doi.org/10.1016/S2542-5196(20)30298-9

63. Pew Research Center, June 29, 2021, “Religion in India: Tolerance and Segregation”

64. Prabhu, Shravan, Keerthana Anthikat Sukesh, Srishti Mandal, Divyanshu Sharma, and Vishwas Chitale. 2025. How Extreme Heat is Impacting India: Assessing District-level

Heat Risk. New Delhi: Council on Energy, Environment and Water. https://www.ceew.in/sites/default/files/ceew-how-extreme-heat-is-impacting-india-final-web-file.pdf

65. Press Information Bureau (PIB). (2025a, January 2). *India submits its 4th Biennial Update Report to the United Nations Framework Convention on Climate Change* [Press release]. Ministry of Environment, Forest and Climate Change. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2089589

66. Press Information Bureau. (2025, November 30). *2025: A defining year for India's growth – India's Goldilocks moment: High growth, low inflation* [Press note]. Government of India. https://www.pib.gov.in/PressNoteDetails.aspx?NoteId=156770&ModuleId=3&reg=3&lang=1

67. Press Information Bureau (PIB). (2025b, July 14). *India's Renewable Rise: Non-Fossil Sources Now Power Half the Nation's Grid* [Press release]. Ministry of New and Renewable Energy. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2144627

68. PIB. (2019). India need to increase its per capita energy consumption at least 2.5 times to provide affordable, reliable and sustainable energy to all her citizen [Press release]. https://www.pib.gov.in/Pressreleaseshare.aspx?PRID=1577011&reg=3&lang=2

69. Press Information Bureau. (2025, July 14). *India's renewable rise: Non-fossil sources now power half the nation's grid* [Press release]. Government of India. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2144627

70. Press Information Bureau. (2021, October 31). *National statement by Prime Minister Shri Narendra Modi at COP26 in Glasgow* [Press release]. Press Information Bureau, Government of India. https://www.pib.gov.in/PressReleasePage.aspx?PRID=1768712

71. Press Information Bureau. (2025, May 1). *Celebrating nine years of Pradhan Mantri Ujjwala Yojana (PMUY)* [Press note]. Ministry of Petroleum and Natural Gas, Government of India. https://www.pib.gov.in/PressNoteDetails.aspx?NoteId=154355&ModuleId=3&reg=3&lang=2

72. Press Information Bureau. (2024, July 19). *Implementation of PM-JANMAN* [Press release]. Ministry of Tribal Affairs, Government of India. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2036830

73. Reserve Bank of India. (n.d.). *India KLEMS database*. https://www.rbi.org.in/scripts/klems.aspx

74. Ritchie, H., Rosado, P., & Roser, M. (2024). *Per-capita greenhouse gas emissions* [Data set]. In *CO and greenhouse gas emissions*. Our World in Data. https://ourworldindata.org/grapher/per-capita-ghg-emissions

75. Ritchie, H., Rosado, P., & Roser, M. (2023). *Total electricity generation per person* [Data set]. In *Energy*. Our World in Data. https://ourworldindata.org/grapher/per-capita-electricity-generation

76. Romanello, M., Walawender, M., Hsu, S.-C., Moskeland, A., Palmeiro-Silva, Y., Scamman, D., … & Watts, N. (2025). Health and climate change in India: 2025 Lancet Countdown data sheet. Lancet Countdown. https://lancetcountdown.org/wp-content/uploads/2025/10/India_Lancet-Countdown_2025_Data-Sheet-2.pdf

77. Roxy MK, Ghosh S, Pathak A, Athulya R, Mujumdar M, Murtugudde R, Terray P, Rajeevan M. A threefold rise in widespread extreme rain events over central India. Nat Commun. 2017 Oct 3;8(1):708. doi: 10.1038/s41467-017-00744-9 PMID: 28974680; PMCID: PMC5626780

78. Smith, C. J., Forster, P. M., Samset, B. H., & Liu, X. (2023). Future pathways of carbon dioxide emissions and warming depend strongly on near-term mitigation actions. *Nature Climate Change, 13*, 780–787. https://doi.org/10.1038/s41558-023-01848-5

79. Singhal, A., Sharma, S., & Garg, T. (2021). *Transitioning to super energy-efficient room air conditioners: Fostering ICAP implementation*. Alliance for an Energy Efficient Economy. https://aeee.in/wp-content/uploads/2021/11/transitioning-to-Super-Energy-Efficient-Room-Air-Conditioners.pdf

80. United Nations Development Programme. (2024). *Human Development Report 2023/2024: Breaking the gridlock – Reimagining cooperation in a polarized world* [Report]. UNDP. https://hdr.undp.org/system/files/documents/global-report-document/hdr2023-24reporten.pdf

81. UNFCCC. (n.d.). *The Paris Agreement* [Treaty web page]. United Nations Framework Convention on Climate Change. https://unfccc.int/process-and-meetings/the-paris-agreement

82. United Nations Population Fund. (2024). *India: World population dashboard*. https://www.unfpa.org/data/world-population/IN

83. United Nations Development Programme. (2024). *India's human development continues to make progress, ranks 130 out of 193 countries*. https://www.undp.org/india/press-releases/indias-human-development-continues-make-progress-ranks-130-out-193-countries

84. World Intellectual Property Organization. (2024). *Global Innovation Index 2024* [Report]. WIPO. https://www.wipo.int/global_innovation_index

85. World Bank. (2024). *GDP per capita, PPP (current international $) – India (NY.GDP.PCAP.PP.CD)* [Data set]. The World Bank Group. https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?locations=IN

86. World Bank. (n.d.). *Energy use (kg of oil equivalent) per $1,000 GDP (constant 2021 PPP) (Indicator code: EG.USE.COMM.GD.PP.KD)*. World Development Indicators, based on IEA Energy Statistics Data Browser. https://data.worldbank.org/indicator/EG.USE.COMM.GD.PP.KD

87. World Bank. (2024). *World Development Indicators* [Data set]. World Bank Group. https://databank.worldbank.org/source/world-development-indicators

88. World Economics. (2024). *Global growth rankings: Economies by contribution to world GDP growth* [Web page]. World Economics Ltd. https://www.worldeconomics.com/Rankings/Economies-By-Global-Growth.aspx

89. World Meteorological Organization. (2024). *Record carbon emissions highlight urgency of global greenhouse gas watch*. https://wmo.int/media/news/record-carbon-emissions-highlight-urgency-of-global-greenhouse-gas-watch

90. World Bank. (2023). *Advancing climate adaptation: Building resilience to climate change in India*. https://www.worldbank.org/en/country/india/brief/advancing-climate-adaptation-building-resilience-to-climate-change-in-india

सत्यमेव जयते

NITI Aayog