सत्यमेव जयते
NITI Aayog

SCENARIOS TOWARDS VIKSIT BHARAT AND NET ZERO

SECTORAL INSIGHTS: POWER

(VOL. 7)

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Message from Working Group Chair Power Sector

India's power sector stands at the core of the nation's development and climate ambitions. As India advances towards Viksit Bharat @2047 and pursues its commitment to achieve Net Zero emissions by 2070, the electricity system will be central to enabling economic growth, industrial competitiveness, raising living standards and economy-wide decarbonisation. Ensuring reliable, affordable, and sustainable electricity for a rapidly growing economy remains a strategic national priority.

Electricity demand is set to rise sharply with urbanisation, industrialisation, digitalisation, and the electrification of transport, buildings, and industry. Meeting this demand while reducing emissions requires a carefully balanced approach that ensures energy security, system reliability, and affordability for all consumers, while accelerating low-carbon transition.

Renewable energy will form the backbone of India's future electricity system, supported by large-scale deployment of energy storage, strengthened transmission networks, and modernised grid operations. At the same time, clean firm power sources will play a critical role in ensuring system stability. Nuclear energy, as a reliable, low-carbon source of baseload and generation, will be an important component of India's long-term power mix. Expanding nuclear capacity with ability to flex the generation, including advanced and small modular reactor technologies, can provide dependable electricity while complementing high shares of variable renewable energy.

In the near to medium term, coal will continue to play a role in maintaining grid reliability and meeting rising electricity demand, particularly during periods of high system stress. The focus, therefore, must be on improving the efficiency, flexibility, and environmental performance of the existing coal fleet, while avoiding long-term lock-ins that could undermine the net-zero pathway.

This report presents a rigorous, integrated assessment of India's power sector pathways under current policy and net zero scenarios. By linking economy-wide electricity demand with detailed capacity expansion and system operation modelling, it provides clear insights into the evolving role of renewables, storage, nuclear, coal, and grid infrastructure. The report highlights the critical role of flexibility, storage, and grid modernisation in enabling high penetration of variable renewable energy and underscores the importance of timely investments and policy sequencing in minimising system costs and risks.

Promoting the procurement of capacity and energy through market-based instruments will be essential to keep the system costs lower. In addition, greater thrust on distribution reforms aiming at efficiency improvements, digitalisation coupled with data analytics and commercial orientation in governance of the utilities will be of paramount importance for timely mobilising the necessary investments in whole of the value chain and for necessary upgrades and augmentation of networks to improve reliability of supply.

The findings reinforce that low-carbon transition in the power sector is the single most powerful lever for achieving economy-wide emissions reduction. A cleaner electricity grid amplifies the benefits of electrification in transport and industry, enhances energy security by reducing fossil fuel imports, and supports domestic manufacturing and job creation.

I commend the authors for their analytical rigour and for presenting a balanced and pragmatic roadmap for India's power sector transition. This report provides valuable insights for policymakers, regulators, utilities, investors, and other stakeholders, and will support informed decision-making as India charts a resilient, affordable, and sustainable electricity future aligned with its developmental and strategic priorities.

Alok Kumar

(Alok Kumar)
Former Union Power Secretary

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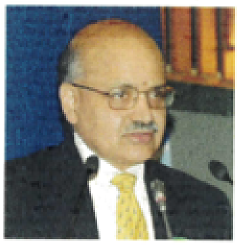

FOREWORD

The power sector is at the heart of India's aspirations to become a developed country. For a growing economy like ours, electricity demand is expected to increase over the next few decades. The power sector is the main driver for achieving the goal of Net Zero emissions. Power sector has a central role in enabling economic growth, industrial competitiveness, and economy wide transition, while ensuring reliability, and affordability.

Power systems are already under transition. The cost of clean energy technologies continues to decline. We are promoting the adoption of solar based electricity generation at all levels: utility scale, household rooftop PV systems and also agricultural feeders. The government has also provided a major thrust to nuclear power by amending the legislative framework to permit private sector participation.

NITI Aayog, through the inter-ministerial working group on the power sector, undertook a rigorous, integrated assessment of India's power sector pathways. It connects comprehensive energy demand forecasts with detailed power system planning. The report presents a perspective on the evolution of capacity expansion, generation mix, storage solutions, transmission networks, and grid emissions. Large-scale deployment of energy storage strengthened transmission networks and modernised grid operations will be critical to achieve the objective of a modern, reliable and responsive grid. Nuclear energy will play an important role as a reliable, low-carbon source of baseload generation. In the near to mid-term, an efficient, flexible coal power is necessary to ensure grid stability and reliability to meet rising electricity demand.

I thank Shri Alok Kumar for his leadership in guiding the report, drawing on his vast experience in the sector. My appreciation for Shri Ghanshyam Prasad, Chairman, CEA and his colleagues for their close involvement with NITI in this study. I also thank all the working group members for their keen involvement in this report. I congratulate NITI Aayog team led by Dr. Anshu Bharadwaj, Shri Rajnath Ram, Shri Venugopal Mothkoor, Dr. Anjali Jain and Shri Nitin Bajpai, for their outstanding efforts in developing a suite of models to deliver India's comprehensive energy transition roadmap.

This report provides valuable insights for policymakers, regulators, utilities, investors, and other stakeholders. It will support informed decision-making as India charts a resilient, affordable, and sustainable electricity future.

Dated: 4th February, 2026

[B.V.R. Subrahmanyam]

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एक कदम स्वच्छता की ओर

घनश्याम प्रसाद
अध्यक्ष तथा पदेन सचिव भारत सरकार
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FOREWORD

India's commitment to achieve Net-Zero greenhouse gas emissions by 2070 marks a significant milestone in the country's long-term strategy for sustainable and inclusive economic development. This commitment reflects India's determination of pursuing economic growth while addressing the challenges of climate change and ensuring reliable, affordable and secure energy for all.

The power sector has a central role in achieving this objective. While it is a significant source of emissions, the sector also offers substantial potential for decarbonisation through large-scale deployment of renewable energy, integration of energy storage systems, adoption of clean and emerging technologies such as Carbon Capture Utilization and Storage (CCUS), improvement in energy efficiency and development of a flexible and resilient electricity system. The transition of the power sector will also be critical in enabling emissions reduction across other sectors of the economy.

In this context, the studies undertaken to examine pathways for the power sector up to 2070 assume considerable importance. These studies provide a comprehensive and evidence-based assessment of possible transition pathways, outlining the technological, infrastructural and policy interventions required to achieve the Net-Zero target, while ensuring grid reliability, system adequacy and affordability. By enabling decarbonisation, fostering innovation and supporting inclusive development, these efforts will also contribute significantly in achieving India's vision for Viksit Bharat @ 2047.

The guidance provided by Shri Alok Kumar, Head of the Committee of the Inter-Ministerial Working Group on the Power Sector, is gratefully acknowledged. His leadership and direction have contributed significantly to the development of the analytical framework and overall approach of these studies.

I would also like to place on record my appreciation for the concerted efforts of the officers of the Central Electricity Authority and NITI Aayog. Their technical expertise, inter-institutional coordination and sustained efforts have been instrumental in bringing out the report.

It is expected that the outcomes of this report will serve as a useful reference for policymakers, planners, utilities and other stakeholders, and will support informed decision-making towards the achievement of India's Net-Zero target by 2070.

(Ghanshyam Prasad)

New Delhi
02 February 2026

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List of Abbreviations

AT&C	Aggregate Technical & Commercial Losses
AUSC	Advanced Ultra Supercritical
BCM	Billion Cubic Metres
BEE	Bureau of Energy Efficiency
BESS	Battery Energy Storage System
BPKMs	Billion Passenger-Kilo Metres
BTKMs	Billion Tonne-Kilo Metres
BU	Billion Units
BWR	Boiling Water Reactor
CAGR	Compounded Annual Growth Rate
CAPEX	Capital Expenditure
CCC	Carbon Credit Certificate
CCTS	Carbon Credit Trading Scheme
CCUS	Carbon Capture, Utilisation and Storage
CEA	Central Electricity Authority
CKM	Circuit Kilo Metres
CPS	Current Policy Scenario
CSP	Concentrated Solar Power
CUF	Capacity Utilisation Factor
DAM	Day Ahead Market
DER	Distributed Energy Resources
DISCOMs	Distribution Companies
DSM	Deviation Settlement Mechanism
EPS	Electric Power Survey
FBR	Fast Breeder Reactor
GDAM	Green Day-Ahead Market
GDP	Gross Domestic Product

GEC	Green Energy Corridor
GENCOs	Generation Companies
GHG	Green House Gas
GTAM	Green Term-Ahead Market
GW	Gigawatt
HNU	High Nuclear
HRE	High Renewable Energy
IESS	India Energy Security Scenarios
IGCC	Integrated Gasification Combined Cycle
IMWGs	Inter-Ministerial Working Groups
LEM	Local Energy Market
LWR	Light Water Reactor
MMT	Million Metric Tonne
$MtCO_2e$	Million Tonnes of Carbon Dioxide Equivalent
MTPA	Million Tonne Per Annum
MU	Million Units
NDC	Nationally Determined Contribution
NEP	National Electricity Policy
NISE	National Institute of Solar Energy
NIWE	National Institute of Wind Energy
NSGM	National Smart Grid Mission
NZS	Net Zero Scenario
OSOWOG	One Sun One World One Grid
PHWR	Pressurised Heavy Water Reactor
PIB	Press Information Bureau
PLF	Plant Load Factor
PLI	Production Linked Incentive
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyaan
PPA	Power Purchase Agreement
PPP	Public-Private Partnership
PSP	Pumped Storage Plant
PV	Photovoltaic
PWR	Pressurised Water Reactor
R&D	Research And Development

RDSS	Revamped Distribution Sector Scheme
REC	Renewable Energy Certificate
RES	Renewable Energy Sources
RPO	Renewable Purchase Obligation
RTM	Real Time Market
RTS	Rooftop Solar
TBCB	Tariff Based Competitive Bidding
TRANSCOs	Transmission Companies
SEB	State Electricity Board
SERCs	State Electricity Regulatory Commissions
SMR	Small Modular Reactor
SPV	Solar Photovoltaic
TAM	Term Ahead Market
T&D	Transmission And Distribution
TIMES	The Integrated MARKAL-EFOM System
ToU/ToD	Time of Use/Time of Day
TWh	Terawatt-Hour
UDAY	Ujwal Discom Assurance Yojana
UK	United Kingdom
US	United States of America
VPPAs	Virtual Power Purchase Agreements
VPPs	Virtual Power Plants
VRE	Variable Renewable Energy
WACC	Weighted Average Cost of Capital

Executive Summary

India's development and climate goals increasingly hinge on one system: electricity. As India moves toward Viksit Bharat 2047 and Net Zero 2070, the power sector's growth will determine whether growth can be both inclusive and sustainable. Reliable, affordable, and progressively cleaner electricity is essential to improve living standards, raise productivity, and unlock a low-carbon transition across transport, buildings, and industry.

Over the past two decades, the power sector has delivered major gains: universal household electrification, rapid expansion of the national grid, and a sustained scale-up of renewable capacity. India has also accelerated its shift toward low-carbon electricity - by July 2025, over 50% of installed utility-scale electricity capacity is based on non-fossil fuel-based generation technologies, enabling India to meet its revised Nationally Determined Contribution (NDC) target five years ahead of schedule (PIB, 2025). With nearly 258 GW of renewable energy capacity installed by December 2025, India has emerged as the world's fourth-largest renewable energy market, reflecting the scale and momentum of its clean energy expansion.

The next phase, however, is more complex. Demand will rise sharply with urbanisation, cooling, digitalisation, electric mobility, and green hydrogen, and the system is required to absorb much higher shares of variable renewables. Meeting these twin pressures will require not just adding capacity, but strengthening flexibility and resilience through storage, transmission expansion, modern grid operations, and financially viable distribution to ensure that clean electricity continues to be reliable and affordable as it scales.

Against this complex and dynamic backdrop, NITI Aayog constituted an Inter-Ministerial Working Group to examine India's long-term power sector transition, with a mandate to assess future electricity demand, low-carbon supply options, system reliability, and investment requirements under various scenarios. To quantify pathways that couple development with cleaner power, this study models India's electricity transition through 2070 under two lenses: a Current Policy Scenario extending today's trajectory, and an ambitious Net-Zero Scenario aligned with national 2070 net-zero goals.

Key Modelling Insights

Integrated Modelling Approach: The analysis adopts an integrated energy modelling framework, in which electricity demand is projected using macroeconomic growth, urbanisation trends, sectoral elasticities, and technology adoption patterns. This is coupled with detailed power sector planning models to derive system outcomes. End-use demand across transport, industry, buildings, cooking, and agriculture is projected using The Integrated MARKAL-EFOM System (TIMES) and India Energy Security Scenarios (IESS) models, while capacity expansion, generation, storage, and system operations are simulated using the TIMES and ORigin-DEstiNAtion data exploration (ORDENA) power-sector models.

The two power sector models are aligned on demand projections and reconciled on capacity and generation results. The use of two independently structured power sector models enhances the robustness and credibility of the decarbonisation pathways.

Table E.1 provides a snapshot of power sector by 2050 and 2070 under two scenarios modelled in this study.

Electrification-Led Demand Surge: India's energy transition will be defined by rapid electrification across the economy, pushing electricity demand on to a much steeper trajectory. Electricity's share in final energy is projected to increase from ~21% in 2025 to nearly 40% in the Current Policy Scenario (CPS) and 60% in the Net Zero Scenario (NZS) by 2070, driven by high EV penetration, greater use of electric industrial heat (heat pumps/electric boilers), and a shift toward electric cooking.

As a result, per-capita electricity consumption increases from 1,400 kWh in 2025 to 7,000 - 10,000 kWh by 2070, moving toward levels seen in advanced economies such as France and the Republic of Korea. This reflects both rising living standards and a structural shift toward electricity as the dominant energy carrier.

Crucially, this electrification-led demand expansion also defines the pace and depth of India's economy-wide low-carbon transition. As mobility, industry, and buildings shift towards electric and hydrogen-based systems, the climate benefit of these transitions becomes critically dependent on the emissions intensity of the power grid itself. A rapid decline in grid CO_2 intensity enables deep abatement across end-use sectors, while a persistently carbon-intensive grid would severely constrain their mitigation potential.

Table E.1: A snapshot of power sector by 2050 and 2070

Indicators	2023-24	Current Policy Scenario		Net Zero Scenario	
		2050	2070	2050	2070
Total Electricity Consumption (TWh)	1541	6,544	9,718	8,070	12,997
Per-capita Electricity Consumption (kWh)	1,400	~4,800	~7,400	~6,400	~10,000
Total Capacity (GW) (including captive)	523	2,500-2,800	4,650-4,750	3,800-3,830	6,800-7,350
VRE (Solar + Wind) Capacity (GW) (including captive)	136	1,890-2,200	4,150-4,200	3,150-3,200	6,150-6,700
Share of Non-fossil Fuel-Based Generation Capacity (including captive)	40%	81-83%	94-95%	89%	98%
Grid Emission Factor ($kgCO_2/kWh$)	0.727	0.328	0.067	0.257	0.0
BESS Capacity (GW)	<0.5	420-520	1,300–1,400	900-1,150	2,500–3,000
Pumped Hydro Capacity (GW)	3.3	117	131-163	117	150-165
Total Investment Required (Trillion USD)		3.5 (2025-2050)	5.2 (2050-2070)	5.15 (2025-2050)	9 (2050-2070)

Scale and Composition of Capacity: By 2070, total installed capacity is projected to be nine times in current policy scenario and 14 times in net-zero scenario. The capacity mix shifts decisively toward Variable Renewable Energy (VRE): the share of RE capacity (utility + captive) grows from about 43% in 2025 to about 90–93% by 2070. Solar PV becomes the backbone with capacity reaching 3250 GW – 5500 GW under two scenarios; onshore wind exceeds 1,000 GW, with offshore wind of about 50–70 GW as identified potential is tapped.

The VRE-led transition extends beyond utility-scale projects to include decentralised solutions such as rooftop solar, building-integrated PV, agrivoltaics, and other behind-the-meter resources. These options reduce land-use pressures, ease grid congestion, strengthen resilience, and support more inclusive energy participation, particularly in urban, agricultural, and industrial areas. By improving alignment between local generation and demand, distributed renewables complement utility-scale VRE while enhancing energy access and local economic benefits.

However, penetration of high variable renewables re-shapes system design and operations, making energy storage and flexibility essential. Battery storage is projected to expand from negligible levels today to about 1,300–1,400 GW under Current Policy Scenario and 2,500–3,000 GW under Net Zero Scenario by 2070, while pumped hydro reaches around 150–160 GW. These resources are critical for adequacy, managing variability, and maintaining reliability in a renewables-dominated grid.

Nuclear is Critical for Providing Firm and Clean Power: Nuclear energy emerges as a strategic pillar of India's long-term power transition, scaling from 8.8 GW in 2025 to over 300 GW by 2070, providing firm, dispatchable, low-carbon power that is essential for maintaining system reliability in a renewables-dominated grid.

Beyond large conventional reactors, newer nuclear solutions, particularly Small Modular Reactors (SMRs), assume a critical role by enabling flexible and modular deployment, enhancing safety and cost scalability, and supporting decarbonisation in hard-to-abate sectors.

Resources Footprint: Land requirements rise with the build up of Variable Renewable Energy (VRE), but remain a modest share of national wasteland - nearly 7.2% in Current Policy Scenario and 12% in Net Zero Scenario of current wasteland by 2070. Nuclear has compact direct land use but requires safety buffers. Water intensity declines over time as fossil-fuel powered thermal shares fall, as solar/wind are minimal water users.

Investment Imperative: The scale of transformation implied by India's power sector transition is unprecedented and fundamentally capital-intensive. Cumulative investment requirements reach approximately USD 8.79 trillion in Current Policy Scenario and USD 14.23 trillion in Net Zero Scenario by 2070. These investment needs extend well beyond generation capacity alone and encompass the rapid deployment of storage systems and large-scale expansion of transmission and distribution networks.

Key Policy Suggestions/Levers

1) Generation & Portfolio Design

- **Scale solar-wind-storage hybrids:** These hybrids must be the default utility product to improve land-use efficiency, reduce curtailment, lower transmission stress, and deliver firmer clean power. This should be operationalised through identification of priority hybrid zones, streamlined land aggregation, single-window clearances and assured transmission build-out.

- **Nuclear as clean firm power:** Implement the SHANTI Act to enable rapid scale-up of nuclear capacity, targeting 100 GW by 2047 and 200-300 GW by 2070, coupled with enabling reforms to support flexible operation while ensuring cost recovery. Operational flexibility in new nuclear plants is required to enable load-following, grid balancing, and better integration with variable renewable energy. Dedicated budgetary support should be ensured for the development and deployment of Small Modular Reactors (SMRs) to accelerate clean firm power and enable decarbonisation of hard-to-abate sectors.
- **Mainstream decentralised and land-neutral renewable energy:** Institutionalise decentralised and land-neutral renewable energy as a core pillar of India's transition, particularly rooftop solar, agrivoltaics, floating solar, and building-integrated PV, to reduce land pressure, T&D losses, and geographic concentration risks. This requires a dedicated Viability Gap Funding (VGF) mechanism for such solutions, standardised Renewable Energy Service Company (RESCO) and utility-led aggregation models.
- **Hydro & pumped storage plants:** Fast track siting, clearances, and viability support for long-duration storage (project preparation facilities; standardised risk allocation in contracts).

2) Transmission & Distribution

- **Transmission build-out:** Expand Green Energy Corridors (GEC) and inter-regional High Voltage DC (HVDC) lines; institute rolling, bankable multi-year Tariff-Based Competitive Bidding (TBCB) pipelines; pre-approve corridors/land banks.
- **Transmission pricing to ensure economic transmission costs:** Transmission tariffs should be designed to recover the actual cost of building and operating the network and to guide efficient system expansion. Avoiding cross-subsidies will prevent distorted generation siting and efficient power flows, leading to better location decisions and lower overall system costs.
- **Distribution transformation:** establish Distribution System Operator (DSO) functions for real-time operations; granular loss reduction targets at feeder level; universal smart metering; Time-of-Day/Time-of-Use (ToD/ToU) tariffs with demand response and dynamic procurement by DISCOMs.
- **Viability Gap Funding (VGF) approach instead of waiver of transmission charges:** VGF should be provided to specific technologies/projects which are temporarily unviable, instead of waiving transmission charges for all users (which hides the real cost of the network).
- **Digitise and automate the grid for high-renewable operations:** Enable end-to-end digitalisation of the electricity system, including universal rollout of smart and prepaid meters, SCADA/ADMS/OMS platforms, feeder automation, and predictive maintenance systems. This should be complemented by deployment of distribution digital twins, operationalisation of the Unified Energy Interface (UEI) for consent-

based data sharing, and standardised protocols for demand response, prosumer settlement, and dynamic tariffs.

3) Policy and Regulatory

- **Deepen power markets:** Expand day-ahead/intraday liquidity; introduce flexibility/ancillary/capacity products; develop electricity derivatives for hedging; scale Local Energy Markets (LEMs) for trading of Distributed Energy Resources (DERs) and congestion relief.
- A strong policy thrust is required to bring captive consumption within the grid supply framework, ensuring fair cost sharing, optimal grid utilisation, and long-term system sustainability.

4) Cross-Cutting

- **Build domestic manufacturing and circular clean energy supply chains:** Strengthen domestic manufacturing depth across solar, wind, storage and electrolyser value chains by expanding PLI schemes beyond modules to batteries, inverters and critical equipment, while closing the loop on PV and battery waste through enforceable recycling and traceability standards. Complement this with VGF and Output Linked Incentive frameworks for large-scale recycling and high-purity material recovery.
- **Research and Development (R&D) and workforce:** Set up clean tech R&D hubs; industry–academia consortia; align national skilling programmes with emerging clean energy industries by reskilling coal and thermal power workers for renewable, storage, and grid-service roles, expanding vocational certification for installers, Operation and Maintenance (O&M) technicians, and digital grid specialists.
- **Land & permitting:** Create state centre land banks and single-window clearances for RE, storage, and transmission; digitise land records; promote leasing/pooling and community benefit sharing; scale floating PV and agrivoltaics to ease land pressure.

5) Finance & Investment Enablement

- Concessional finance is critical to absorb the impact of higher upfront capital expenditure, particularly for emerging and capital-intensive technologies, and to improve overall project bankability. This can be supported through credit enhancement mechanisms, such as sovereign or DFI guarantees, revenue securitisation, and state-backed bonds for DISCOMs and T&D programmes. In parallel, enabling Virtual Power Purchase Agreements (VPPAs) and large-scale corporate procurement through stable and predictable open access rules will help mobilise private investment and lower the cost of capital across the sector.

Economic and Social Co-benefits:

- Energy security and price stability via diversified, domestic resources and moderated exposure to volatile fossil imports.
- Industrial development through "Make in India", clean tech manufacturing (modules, nacelles, towers, cells, electrolysers), creating deep value chains.

- Jobs and entrepreneurship across Engineering, Procurement, and Construction (EPC), Operation & Maintenance (O&M), logistics, digital grid services, recycling, and R&D.
- Regional development through renewable-rich investments, Pumped Storage Projects (PSPs), and associated MSME clusters.

India's power transition is feasible at scale with a storage-backed, digital and market-enabled grid. The Net Zero pathway requires significantly larger clean capacity and storage deployment, stronger nuclear and hydro complements, deep market reforms, and substantially higher investment mobilisation. With deliberate and coordinated policy, financing, and institutional reforms over the coming decade, India can deliver a reliable, affordable, and low-carbon power system that underwrites sustained economic growth, job creation, and climate leadership through 2070.

Background

India stands at a defining juncture in its development journey. As the world's fastest-growing major economy, the nation has set an aspirational target of becoming a developed nation (Viksit Bharat) by 2047. Achieving these goals demands sustained, inclusive economic growth that is tightly aligned with India's long-term climate and sustainability objectives. Electricity lies at the heart of India's transformation. Reliable, affordable, and clean 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.

Over the past two decades, India has achieved remarkable progress in expanding access and improving the reliability of electricity supply. Universal household electrification, large-scale renewable energy deployment, and rapid grid expansion have transformed the sector. As of July 2025, non-fossil electricity sources already account for more than 50% (PIB, 2025) of India's installed utility-scale electricity capacity, achieving the revised NDC target five years ahead of schedule. India's renewable capacity is the fourth largest in the world today, with a capacity of 220 GW as of March 2025.

As the economy grows and urbanisation deepens, electricity demand is projected to rise sharply, driven by increased use of air conditioning, digital services, electric mobility, and industrial electrification. This surge in demand without a transition to low-carbon electricity generation will lead to higher emissions. In 2020, the power sector contributed to roughly 52.07% of energy-related emissions and nearly 39.4% of total national Greenhouse Gas (GHG) emissions (MoEFCC, 2024). Low-carbon transition in the power sector is not only crucial for meeting India's climate targets but also for enabling other sectors to cut their own emissions by accessing cleaner electricity. The challenge, however, is multifaceted. India must carefully balance the three imperatives of the energy trilemma: ensuring energy security amid rising demand; maintaining affordability and reliability for consumers and industry; and advancing sustainability through rapid expansion of low-carbon generation. Achieving this balance will require coordinated policy action, substantial investments, and systemic transformation across generation, transmission, distribution, and power markets. This transformation from a fossil-dominant power system to a non-fossil will require large-scale integration of renewable energy, flexible generation, advanced storage systems, and strong transmission networks to maintain grid stability.

Inter-Ministerial Working Group on Power Sector

Recognising the pivotal role of electricity in India's Net Zero ambition, NITI Aayog constituted multiple Inter-Ministerial Working Groups (IMWGs) to chart sectoral pathways for a 2070 Net

Zero economy. The Working Group on Power Sector has been tasked with examining strategies and developing a roadmap for low-carbon transition of the power sector while ensuring reliability, flexibility, and financial viability.

Chaired by: Sh. Alok Kumar, Chairperson, Former Secretary, Ministry of Power

The broad terms of reference of this WG include:

(i) Assess electricity demand in Net Zero and other scenarios;

(ii) Examine the optimal capacity mix in different scenarios for power sector decarbonisation;

(iii) Assess scenarios for unabated coal use and coal phase-down;

(iv) Examine grid stability considering increasing penetration of intermittent renewable energy and propose measures for ensuring resource adequacy and grid reliability;

(v) Examine transmission infrastructure requirements for future supply mix scenarios;

(vi) Examine the role of advanced technologies such as green hydrogen, Advanced Ultra Supercritical Technology (AUSC), Small Modular Reactors (SMRs), offshore wind, and alternative battery chemistry, etc., in the power sector transition and their competitiveness;

(vii) Examine changes in load pattern considering demand electrification in the transport/ building sector and new emerging loads such as data centres;

(viii) Examine reforms (including regulatory) required in electricity distribution companies (DISCOMs) to facilitate power sector transition and uptake of clean technologies;

(ix) Estimate the total capital investment required for the transition of the power sector.

This study explores how the power sector can enable India's transition to a low-carbon energy system that supports both economic growth and environmental stewardship. It analyses key drivers, challenges, and policy measures to ensure that India's electricity system remains resilient, affordable, and clean, powering the nation's journey toward Viksit Bharat 2047 and Net Zero 2070.

1

INTRODUCTION

1 Introduction

India's power sector is central to the nation's economic growth and development. As the world's third-largest producer and consumer of electricity, India has witnessed a remarkable transformation in its power sector landscape over the past few decades (IBEF). From facing chronic power shortages to becoming one of the fastest-growing and most dynamic sectors globally, the evolution of India's electricity sector reflects broader changes in policy, rapid advancement in technologies, and a shift in demand patterns. Reforms such as the vertical unbundling of State Electricity Boards (SEBs) into Generation Companies (GENCOs), Transmission Companies (TRANSCOs) and Distribution Companies (DISCOMs) (Ministry of Power); the creation of a unified national grid by synchronising all regional grids (Ministry of Power); and the introduction of market-based mechanisms have significantly reshaped the structure and performance of the power sector.

The next phase of this evolution will be even more consequential. As India moves toward a low-carbon future, the power sector will transition from a system historically dominated by fossil fuels to one increasingly powered by low-carbon electricity. This transformation will require not only the rapid expansion of Renewable Energy (RE) but also substantial enhancements in system reliability, flexibility, and resilience. Integrating large volumes of Variable RE (VRE), strengthening transmission networks, deploying advanced storage solutions, and modernising grid operations will be essential to ensure that low-carbon electricity remains both reliable and affordable. Together, these changes will define the next era of India's power sector, where sustainability, reliability, and security stand at the forefront of national electricity planning. However, understanding how the sector has evolved to this point is essential for assessing the scale and nature of the transformation that lies ahead.

Accordingly, this chapter begins by examining the relationship between electricity consumption and economic growth, drawing comparisons with developed countries to illustrate how industrialisation, technological innovation, and strategic policy interventions have historically influenced the electricity system globally. It then traces the evolution of India's power sector, highlighting key milestones from early electrification efforts to recent surge in RE deployment. The chapter provides a detailed assessment of India's current electricity landscape, including generation capacity, transmission infrastructure, and sector-wise consumption patterns, for a clear understanding of its operational and infrastructural foundation. By establishing this historical and structural context, this chapter lays the foundation for analysing India's future energy trajectory and the implications for power sector decarbonisation in subsequent sections.

1.1 ELECTRICITY CONSUMPTION AND ECONOMIC GROWTH

As an economy grows, driven by industrialisation, urbanisation and rising living standards, so does the need for electricity, thus fuelling sectors such as manufacturing, services and infrastructure. In developed nations such as the United States of America (USA), Germany and the United Kingdom (UK), electricity consumption increased during their industrialisation phases, facilitating their economic growth. However, in recent years, these countries have managed to decouple electricity demand from Gross Domestic Product (GDP) growth. This is because of energy efficiency improvements, technological advancements, or sectoral shifts (from manufacturing to services).

For example, electricity consumption in the USA increased consistently from ~300 TWh in 1950 to 3,811 TWh in 2005 (Ritchie, n.d.). It saturated at 3,700-3,900 TWh during 2010-23 even as nominal GDP grew by 82% during this period (World Bank, n.d.). The UK, Germany and France had similar long-term trends of stabilising electricity consumption alongside rising GDP, with some fluctuations in the economic growth over the years, as shown in Figure 1.1.

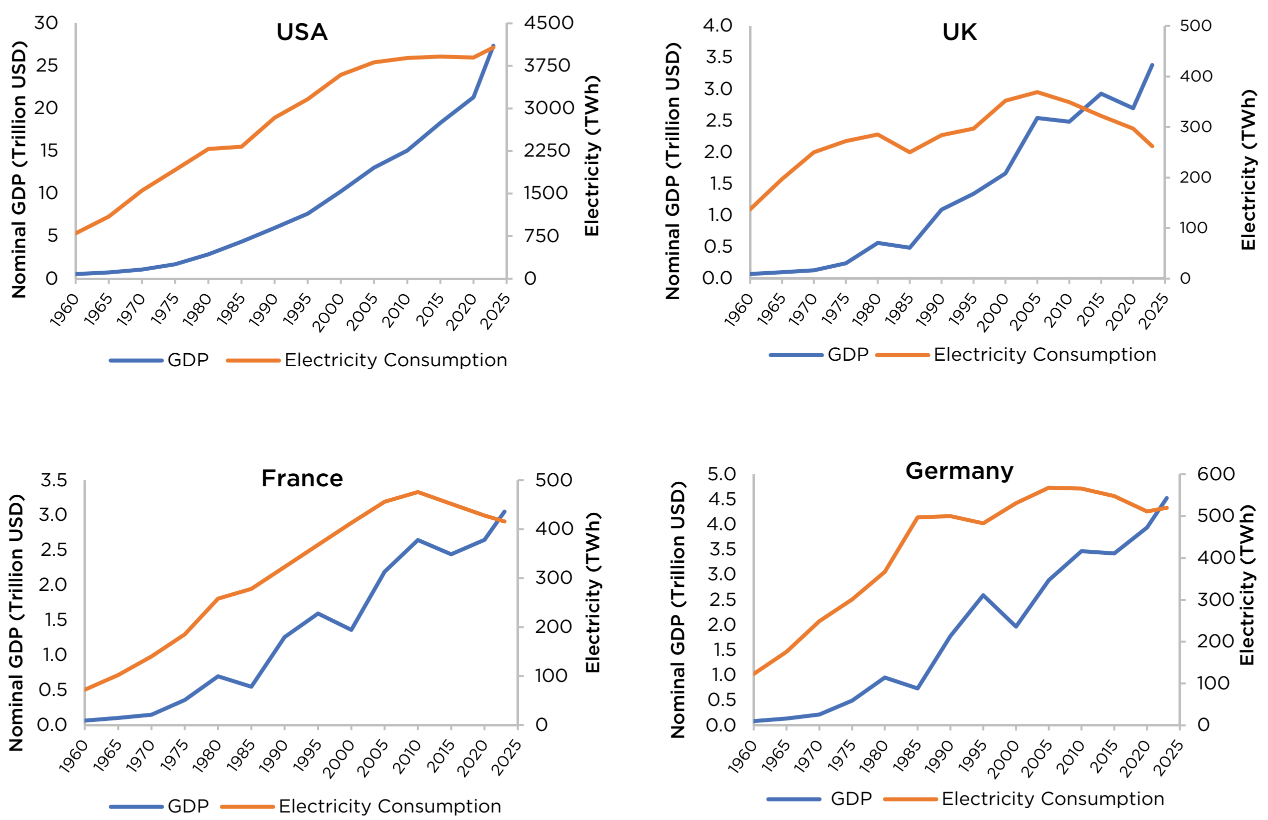


Figure 1.1: Trends of electricity consumption and GDP: USA, UK, France, Germany, highlighting that GDP growth & electricity are decoupled after certain level

Source: *Our World in Data*

The trajectory of developing countries like China and India mirrors that of developed nations during their earlier growth stages. China's nominal GDP increased 93 times (from 191 billion USD in 1980 to 17,795 billion USD in 2023) (World Bank) and had a massive increase in electricity consumption (nearly 35 times) during the same period, reflecting its manufacturing-heavy and energy-intensive economy. India's nominal GDP has grown nearly 19 times (Our World in Data) while electricity consumption has grown nearly 15 times from 1980 to 2023 (as shown in Figure 1.2).

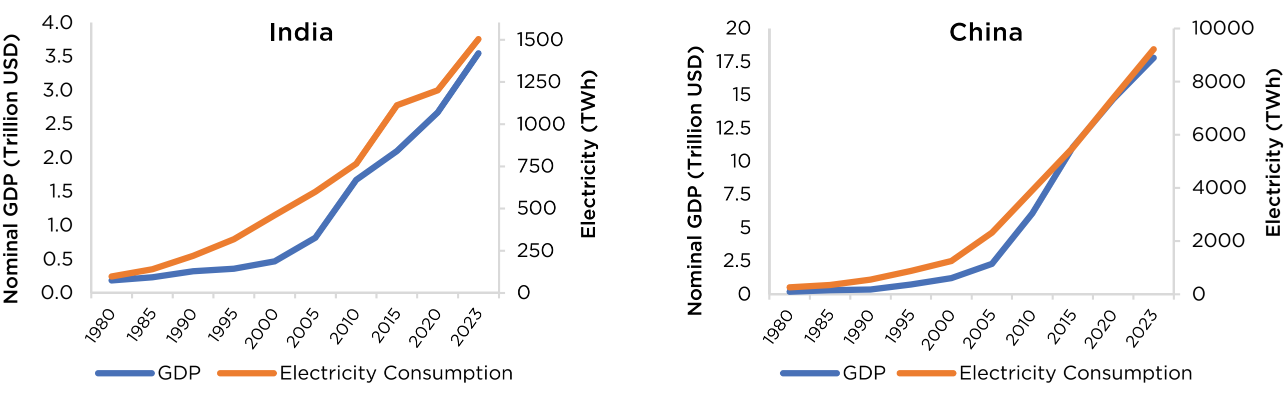


Figure 1.2: Trends of electricity consumption and GDP: India and China

Though India's per capita electricity consumption has increased over the years, it still remains considerably below that of developed nations (as seen in Figure 1.3). India's per-capita electricity consumption stands at 1/10th of the USA's per-capita electricity consumption and remains under half the world average as of 2023.

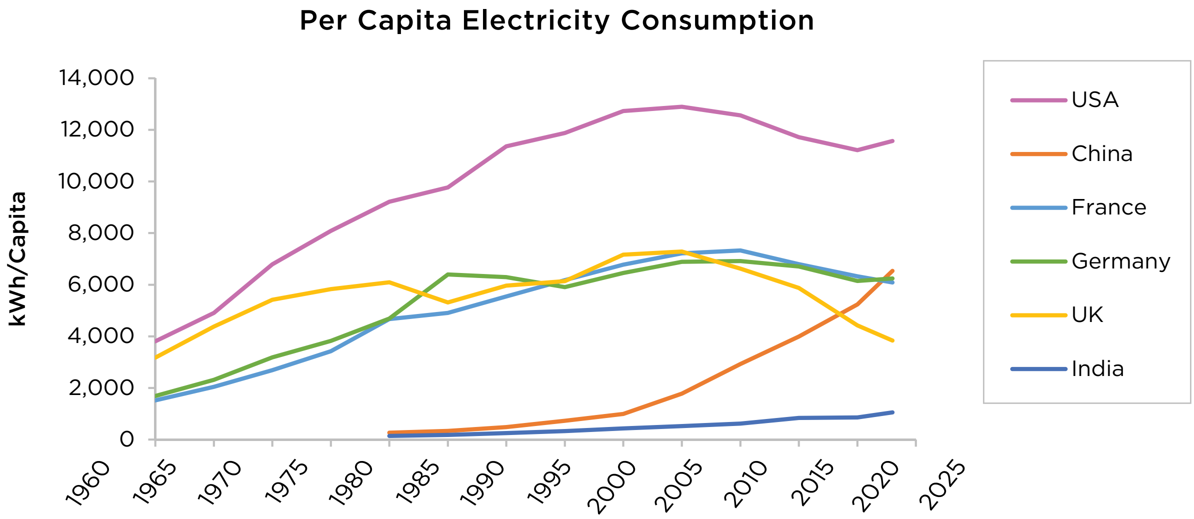


Figure 1.3: Per Capita electricity consumption trend (in kWh per capita) (Ritchie et al, 2023) (For China and India, electricity consumption is shown from 1980 onwards)

A fair comparison would be to examine the electricity consumption of developed nations when their per capita GDP was equivalent to India's current level (2,485 USD in 2023). For Germany, France and the UK, their GDP per capita was in the range of 2,000-3,000 USD between 1965 and 1975 (World Bank). During these years, per capita electricity consumption reported in these countries was in the range of 2,000-5,000 kWh, far exceeding India's per capita electricity consumption of 1,400 kWh in 2024 (Ritchie et al, 2023; CEA, 2025).

India's lower electricity use, which halved from 6.5 kWh/USD in 1980 to 3.1 kWh/USD in 2022, relative to comparable economies reflects falling energy intensity rather than lower levels of development (as seen in Figure 1.4). This means that the Indian economy required less energy to produce a unit of GDP. Energy intensity, however, remains higher than that of developed nations like the USA, indicating potential for improvement. India's electricity intensity has remained relatively stable over the last few years, indicating that the country is still in a phase of industrial expansion.

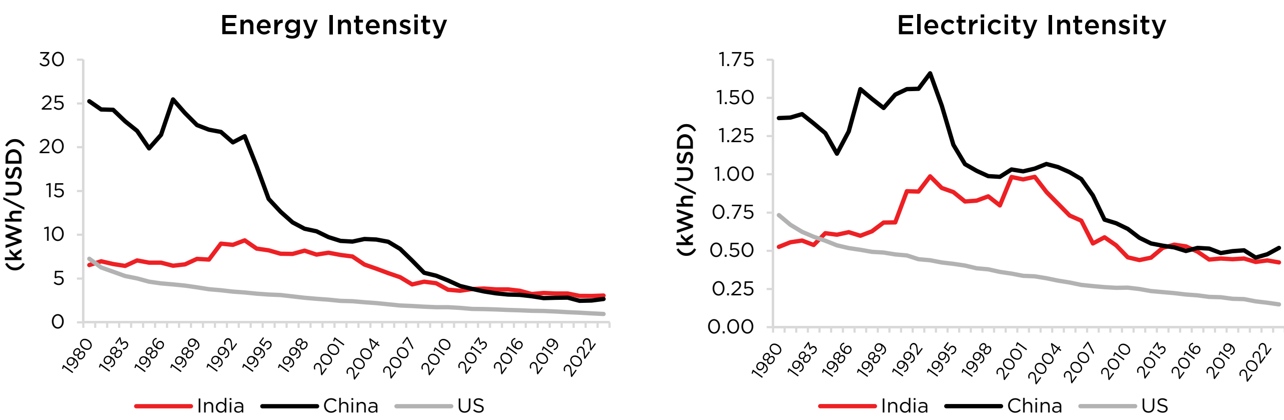


Figure 1.4: Energy and electricity intensity to GDP: USA, China, and India (GDP is taken as current value)

1.2 EVOLUTION OF THE INDIAN POWER SECTOR

The evolution of India's power sector began with the establishment of vertically integrated State Electricity Boards (SEBs) under the Electricity (Supply) Act, 1948. These SEBs were responsible for the entire bundle of services covering generation, transmission, distribution, and retail supply, to expand access to electricity across the country. The establishment of SEBs in the early 1950s drove rapid expansion of the power sector to meet growing demand. This period also saw the implementation of large-scale hydroelectric projects, as well as the construction of thermal and nuclear power stations. The establishment of key organisations such as the National Thermal Power Corporation (NTPC) and the National Hydroelectric Power Corporation (NHPC) in 1975, along with the Nuclear Power Corporation of India (NPCIL) in 1987, further strengthened India's generation capacity.

By the 1990s, the performance of SEBs, especially on the distribution front, started to decline due to multiple reasons. This included high Aggregate Technical & Commercial Losses (AT&C) losses; tariffs that did not adequately reflect the cost of supply; free or underpriced power, limited metering coverage; and low revenue recovery rates. It became evident that the sector needed a complete overhaul. The introduction of the Electricity Regulatory Commissions Act in 1998 was a first step, leading to the creation of independent regulators: the Central Electricity Regulatory Commission (CERC) and State Electricity Regulatory Commissions (SERCs) - to bring transparency in tariff setting and promote consumer interests. This was followed by the landmark Electricity Act of 2003, which mandated the unbundling of SEBs into separate Generation Companies (GENCOs), Transmission Companies (TRANSCOs) and Distribution Companies (DISCOMs), and encouraged competition, open access, and private participation in distribution.

Odisha and Delhi undertook early reforms to address severe financial and operational inefficiencies, with Odisha becoming the first state to unbundle its electricity sector in the mid-1990s and Delhi successfully transitioning to private distribution under a regulated framework in 2002.

To improve service delivery and attract investment in the struggling distribution sector, the government began experimenting with Public-Private Partnership (PPP) models, particularly in urban areas. Odisha and Delhi undertook early reforms to address severe financial and operational inefficiencies, with Odisha becoming the first state to unbundle its electricity sector in the mid-1990s and Delhi successfully transitioning to private distribution under a regulated framework in 2022. Following this, states like Maharashtra, Madhya Pradesh, and Uttar Pradesh implemented Input-Based Distribution Franchisee (IBDF) models, where private players managed day-to-day operations, loss reduction, and customer service, while ownership remained with the government. In recent years, the privatisation of DISCOMs in Union Territories (such as Chandigarh and Dadra & Nagar Haveli) reflects a policy push toward more structured PPP.

Today, while challenges like cross-subsidies, regulatory delays, and DISCOM financial health persist, India's distribution sector is gradually evolving into a more decentralised, technology-driven, and service-focused segment. The growing role of PPP models and regulatory reforms is paving the way for greater consumer empowerment, efficiency, and reliability in power delivery.

The total installed capacity (utility and non-utility) has increased exponentially from 1,362 MW in 1947 to an impressive 523 GW in 2023-24 (CEA, 2025). Similarly, electricity generation in India has grown remarkably over the decades from a modest 4 TWh in the year 1947, to around 1,958 TWh (including 224 TWh generation from captive plants) in 2023-24 (CEA, 2025).

Over the past decade, India's electricity sector has undergone a profound transformation, anchored in its ambition to ensure universal access, energy security, and a low-carbon transition. First, the country added nearly 193 GW of installed power capacity, with cumulative capacity increasing from 249 GW by March 2014 to 442 GW (utilities only) by March 2024 (CEA, 2025). When including captive power plants, the total installed capacity reaches 523 GW by March 2024, placing India among the top power systems globally.

Second, India made significant strides in electrification, transitioning from limited rural access to near-universal coverage through the effective roll-out of Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) and Pradhan Mantri Sahaj Bijli Har Ghar Yojana (SAUBHAGYA schemes). Electrification increased from a meagre 3,061 villages in 1947 to over 597,000 villages, including remote and border regions, by 2018 (CEA, 2025).

Third, beyond generation, India's transmission and distribution infrastructure scaled impressively. The length of Transmission and Distribution (T&D) lines has increased from approximately 11.2 million circuit kilometres (ckms) in 2014 to nearly 14.9 million ckms by 2024, ensuring reliable evacuation of growing RE and regional interconnections (CEA, 2025). This included significant capacity additions in 765 kV high-voltage corridors and the development of Green Energy Corridors (GECs). Crucially, transmission system availability was maintained at >99%, while inter-regional transmission capacity increased to almost 119 GW (Ministry of Power, 2024), enabling real-time balancing and "one-grid-one-nation-one-frequency" operations.

"In 2013, India achieved "One Nation, One Grid, One Frequency," showing the country's strong commitment to providing reliable and efficient electricity to every part of the nation."

1.3 ELECTRICITY SUPPLY-DEMAND POSITION IN INDIA

Over the last few decades, India transitioned from a power-deficient to a power-surplus nation. This transition is underscored by steady improvements in supply capacity and grid integration. From supply deficits of 11.1% in energy and 11.9% in peak seen in 2008-09, it declined to 0.1% in energy and 0% in peak by 2024-25 (see Figure 1.5), indicating improvements in energy generation, supported by growth in T&D infrastructure, bringing energy availability closer to meeting the growing demand.

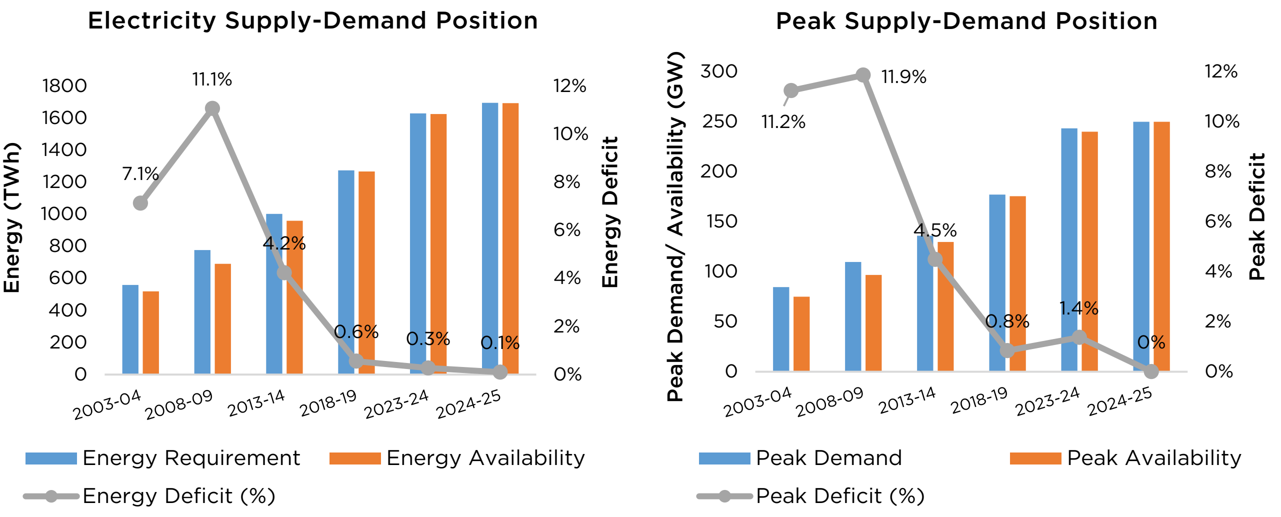


Figure 1.5: Peak and energy requirement, availability, and deficit

This reliable supply position reflects a stronger base-load fleet, adequate reserve margins, and significantly expanded inter-regional and intra-regional transfer capacity. It also underpins India's readiness to meet growing future demand while maintaining high levels of supply reliability.

"In urban areas, the average daily electricity supply has gone up from 22.1 hours in FY14 to 23.4 hours in FY24. Rural areas have seen an even more remarkable progress from 12.5 hours a day to 21.9 hours (PIB, 2025)."

1.4 ELECTRICITY CAPACITY, GENERATION, TRANSMISSION, AND CONSUMPTION IN INDIA

As of December 2025, India's total utility-scale installed capacity stands at 514 GW (CEA 2026), with fossil-based capacity accounting for 48%, RES[1] accounting for 50%, and balance 2% from nuclear (see Figure 1.6). Renewables have registered spectacular growth with overall share increasing from 29% in 2014-15 to 50% by Dec. 2025 (see Figure 1.7), and solar power capacity alone has grown by over 36 times (see Figure 1.8) during this period, positioning the country as the third largest globally in solar capacity (IRENA, 2025).

1 RES - Comprising of solar, wind, small hydro, large hydro, and bio-power

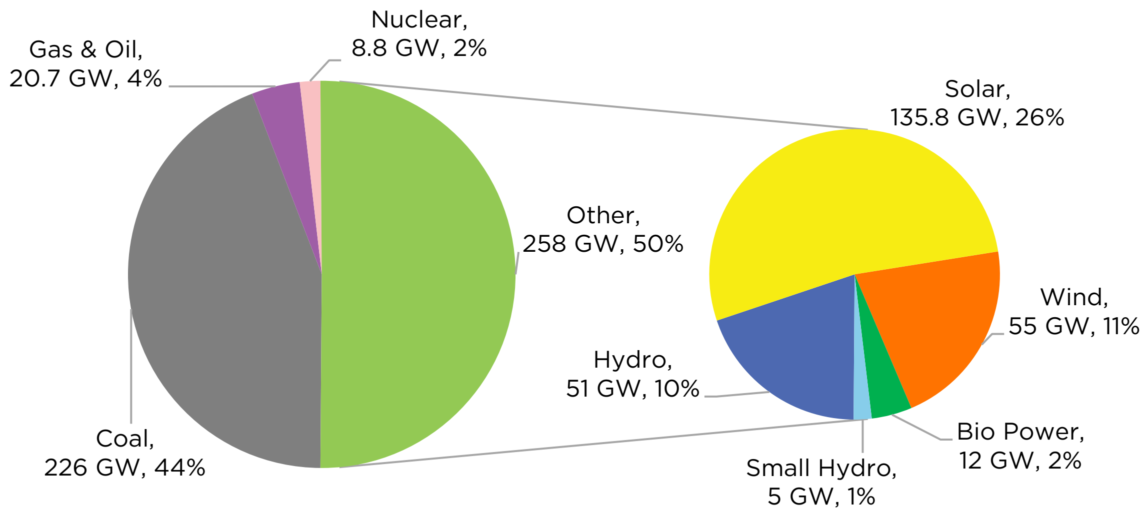


Figure 1.6: India's installed capacity (utility) of electricity generation as of December 2025

Source: *CEA*

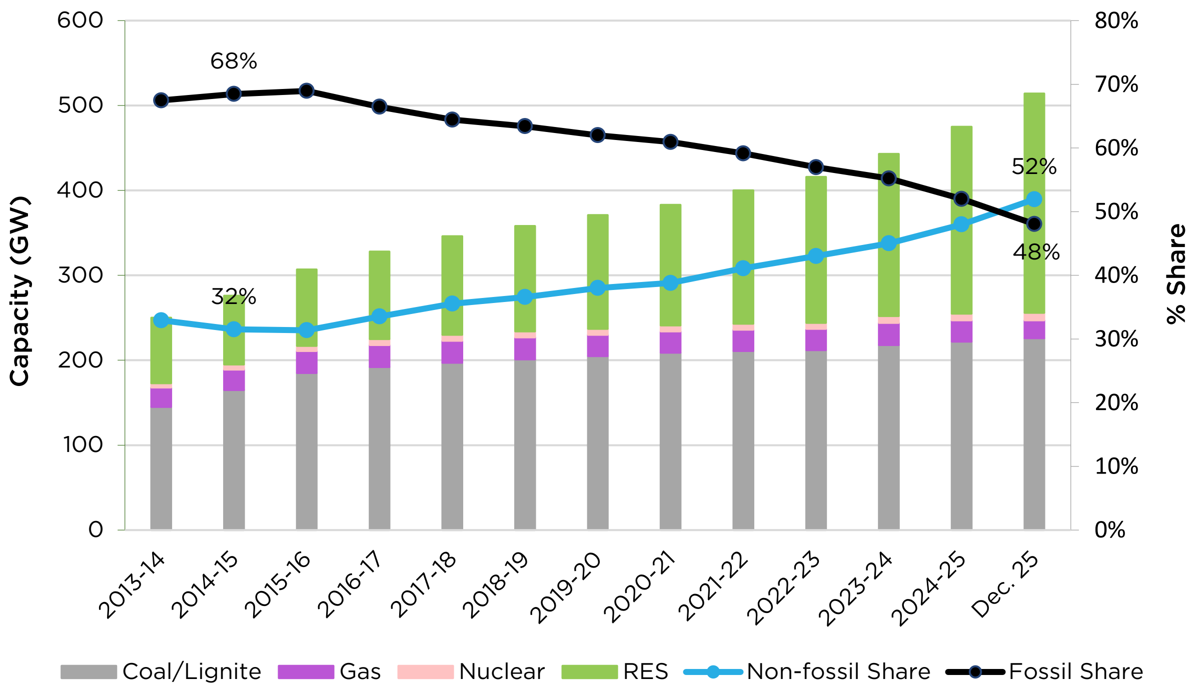


Figure 1.7: Installed capacity/ share of different resource category (utility) shows that Renewable Energy Share (RES) has increased in both absolute numbers and share of capacity

Source: *CEA*

"In 2024–25, 87% of India's new capacity additions came from renewable sources, reflecting a strong shift towards clean energy."

"By July 2025, India had already achieved 50% non-fossil fuel–based installed power capacity, fulfilling one of its key Nationally Determined Contribution (NDC) commitments well ahead of schedule."

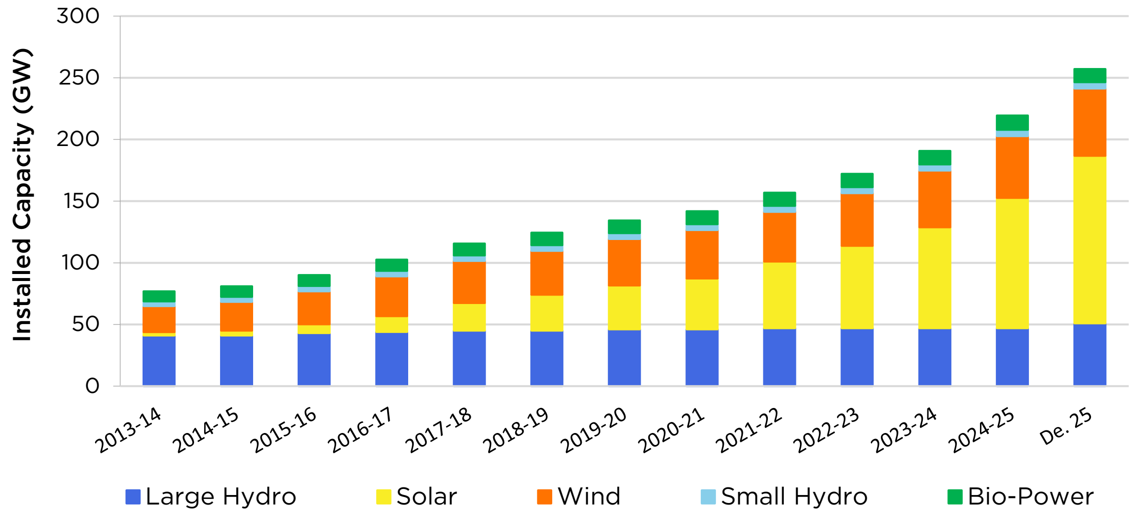


Figure 1.8: Installed capacity of different Renewable Energy resources (utility)

Source: *CEA*

However, despite this impressive growth on the capacity side, the contribution of RE to actual electricity generation has remained modest, with the share increasing from 19.6% in 2013-14 to 22% in 2024-25, as shown in Figure 1.9 (CEA, 2025). Solar and wind have a lower Capacity Utilisation Factor (CUF) than coal, face intermittency and variability related curtailments, and are constrained by grid, flexibility and dispatch limitations. Therefore, rapid expansion of RE capacity has not yet translated into a commensurate rise in its share of generation. Bridging this capacity-generation gap will require investments in storage, flexible resources and transmission, alongside reforms to dispatch and contracting frameworks.

As for India's electricity generation (utilities), it grew from 1,027 BU in 2013-14 to an estimated 1,824 BU in 2024-25 (see Figure 1.9), representing a compounded annual growth rate (CAGR) of 5.36%. The share of captive generation accounted for nearly 11% of the total electricity generation (utility + non-utility) in 2024 (CEA, 2025).

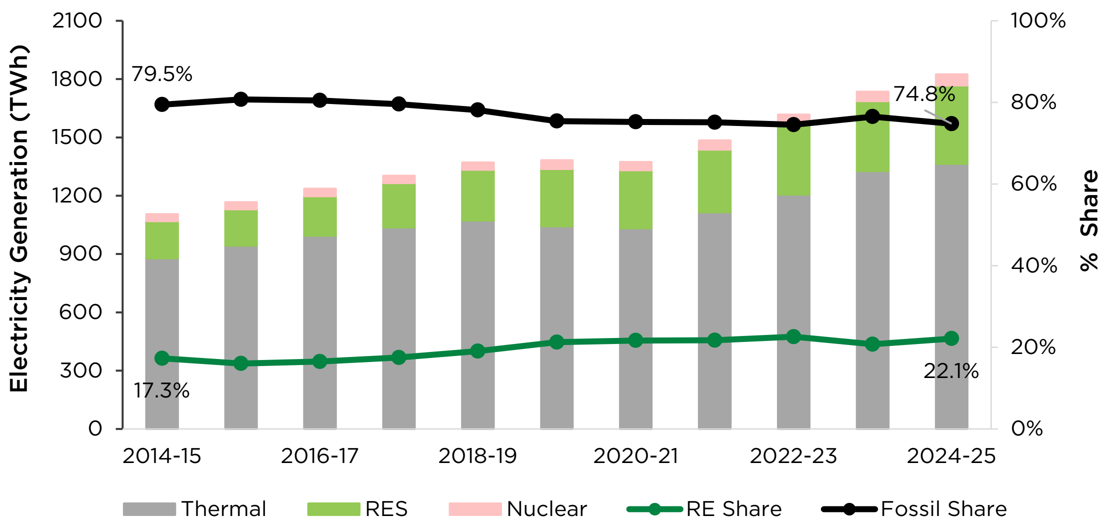


Figure 1.9: Electricity generation by different sources

LHS: Electricity generation from different sources; RHS: % Share of RE and fossil-fuel in total generation

Source: *CEA*

India's nuclear power sector has grown steadily over the past few decades, playing an important role in the country's push for clean and reliable energy. Starting with just one reactor in the 1960s, India now operates 25 nuclear reactors with a total capacity of around 8.78 GW by December 2025. In 2024–25, nuclear power plants generated 56,681 million units (MU) of electricity, achieving an impressive average capacity factor of 87% (NPCIL), which reflects high operational efficiency. An additional 13.6 GW of nuclear capacity is under implementation (PIB, 2025) at various stages, signalling the government's strong commitment to expanding this sector. While nuclear power currently makes up a small portion of India's overall energy mix, it offers a dependable complement to Variable Renewable Energy Sources (VRES) like solar and wind.

"India aims to achieve 100 GW of nuclear power capacity by 2047."

Alongside the expansion of generation capacity, India's power transmission network has significantly evolved to accommodate rising electricity demand (see Figure 1.10). The development of high-capacity infrastructure, including Ultra High Voltage (UHV) lines and Green Energy Corridors (GECs), has enabled efficient inter-regional power transfer. On the distribution front, modernisation efforts have gained momentum, with over 4.95 crore smart meters deployed by December 2025 to improve monitoring and billing efficiency (National Smart Grid Mission). There has been a marked reduction in Transmission and Distribution (T&D) losses, which declined from 23% in 2012-13 to 17.63% in 2023–24 (CEA, 2025), reflecting stronger operational performance and reduced leakages in the system.

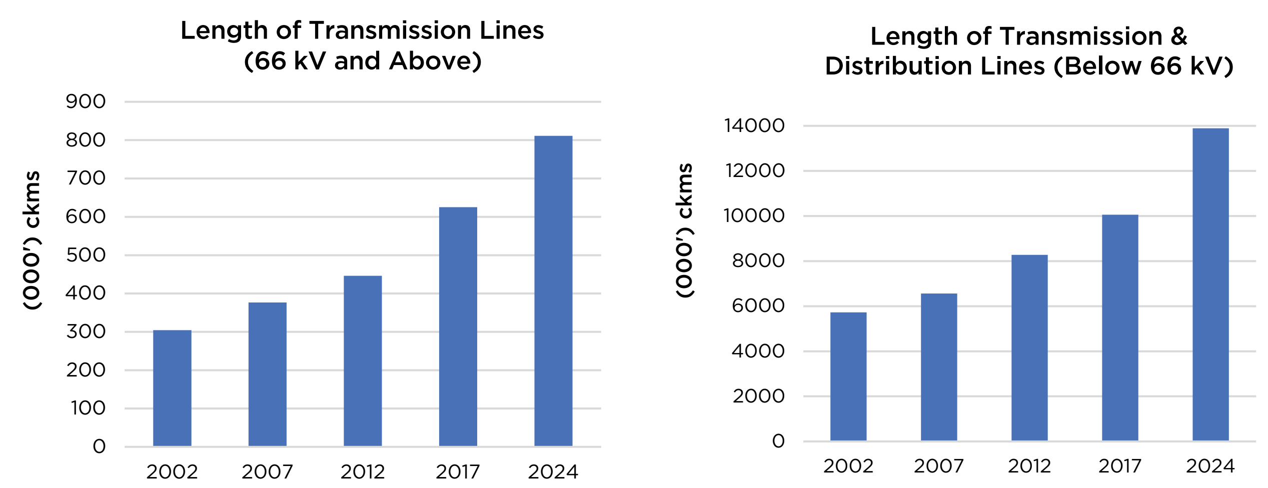


Figure 1.10: Growth of transmission lines in India[2]

With improved efficiency and access, electricity consumption rose from 874 TWh in 2013-14 to 1,540 TWh in 2023-24 at a CAGR of 5.8% (CEA, 2020) (see Figure 1.11). The industrial sector remains the largest consumer, accounting for nearly 42% of total electricity use, and the household (domestic) sector has become the second largest consumer with a share of 24% of total consumption in 2023-24. A significant portion of industrial consumption, around 30%, is met through captive generation rather than supply from DISCOMs.

2 ckms - Circuit Kilometres

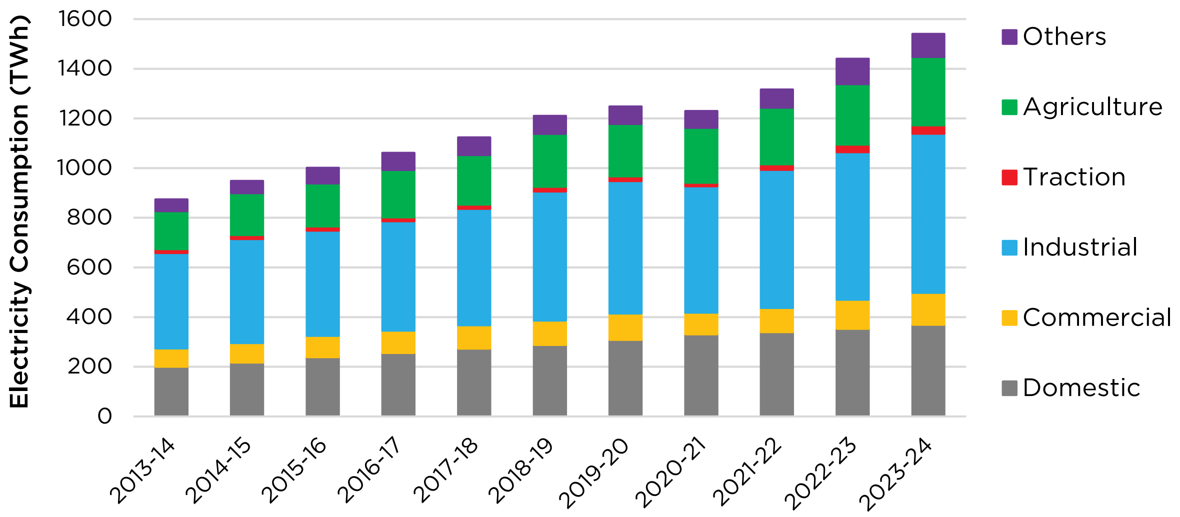


Figure 1.11: Growth of electricity consumption

1.5 ELECTRICITY MARKET: FROM BILATERAL DOMINANCE TO EXCHANGE-LED COMPETITION

The introduction of non-discriminatory Open Access under Section 42(2) of the Electricity Act and the enactment of Power Market Regulations 2010 led to the establishment of Power Exchanges in India.

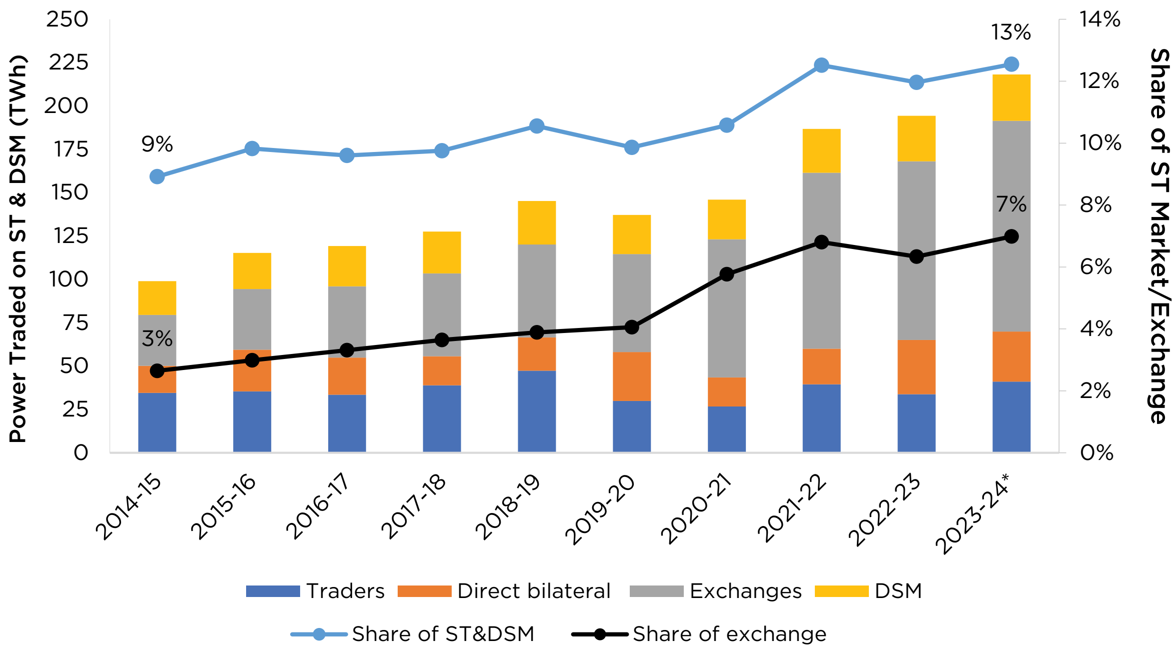


Figure 1.12: Overview of India's short-term power market[3]

3 BU - Billion Units; DSM - Deviation Settlement Mechanism; ST – Short Term

India's Power Market is dominated by long-term PPAs, which constitute around 87.5% of the power generation in FY 2023-24. The short-term market, which constitutes delivery up to one year, met 12.5% of the country's generation in FY 2023-24, as shown in Figure 1.12. Over the last decade, the share of short-term market has remained between 10% to 13% of India's power generation. However, within the short-term market, the share of power exchanges in the overall short-term market has grown from 16% in FY 2011-12 to 56% in FY 2023-24, led by several product innovations discussed subsequently (CERC, 2024). Consequently, the share of exchange-traded electricity in India's total power generation has increased from 2% in FY12 to 7% in FY 2023-24.

To serve the evolving market needs and increase the liquidity in the Spot market, Power exchanges have introduced various products over last 15 years: Term Ahead Market (TAM), Day Ahead Market (DAM), Green Term Ahead Market (G-TAM), Green Day Ahead Market (G-DAM), Real Time Market (RTM) and the Ancillary Services Market (see Figure 1.13). The dedicated green market has incentivised RE-rich states to develop RE capacity beyond their Renewable Purchase Obligations (RPOs), and the same was purchased by RE deficit states and open access consumers to buy green power at competitive prices. Further, recognising the growing share of VRE generation and increased weather-related events impacting the accuracy of demand forecasts, Real Time Market was introduced from 1st June 2020. Through Real Time Market, any variability triggered by RE generation or demand variation can be corrected as close as an hour ahead of actual delivery of power.

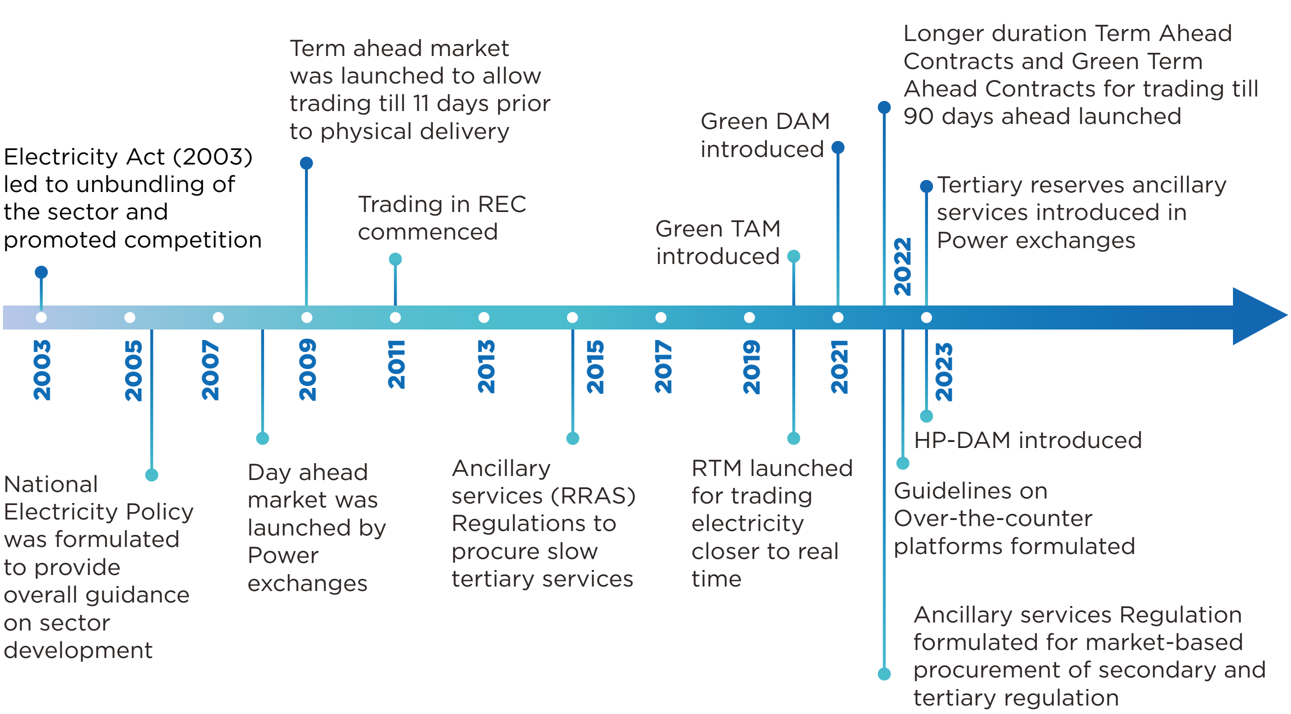


Figure 1.13: Journey of the Indian power market[4]

4 Day Ahead Market; TAM – Term Ahead Market; RTM – Real Time Market; GTAM- Green Term Ahead Market; GDAM – Green Day Ahead Market; RRAS - Reserves Regulation Ancillary Services;

HP-DAM - High Price Day Ahead Market

The Day-Ahead Market (DAM) dominated exchange-based electricity trading in India from its inception until FY19, accounting for over 90% of total exchange volumes, largely due to superior price discovery and liquidity. During this period, the share of power exchanges in the short-term electricity market rose significantly, increasing from about 17% in FY12 to around 56% in FY24 (CERC, 2024).

Following the introduction of the Real-Time Market (RTM), market participation diversified rapidly. Within three to four years of its launch, RTM gained substantial traction, leading to a gradual decline in the share of Day Ahead Market (DAM). By FY 2023–24, DAM's contribution had reduced to about 44% of total exchange-traded electricity, while the shares of RTM and the Term-Ahead Market (TAM) increased to approximately 25% and 28%, respectively. This evolution reflects a maturing market structure in India, broadly aligned with global power market trends, where multiple trading segments coexist to meet varied scheduling and balancing needs.

Further, Green Day Ahead Market (G-DAM), a unique market segment first of its kind in the global power market, was launched in FY22, and this segment is dedicated to the trade of only green power. The G-DAM received a good response; however, with the limited market-based RE capacities in India, the share of G-DAM is just 2% of the total electricity traded by all Exchanges in FY24. Thus, the rising share of new products indicates a healthy trend of product innovation, which has helped to meet the evolving needs of the market participants. Figure 1.15 below shows the trends of Indian Energy Exchange - Day Ahead Market (IEX DAM) prices vis-à-vis the weighted average price in bilateral market. This demonstrates that power exchanges have played a significant role in promoting competition and transparency in power procurement.

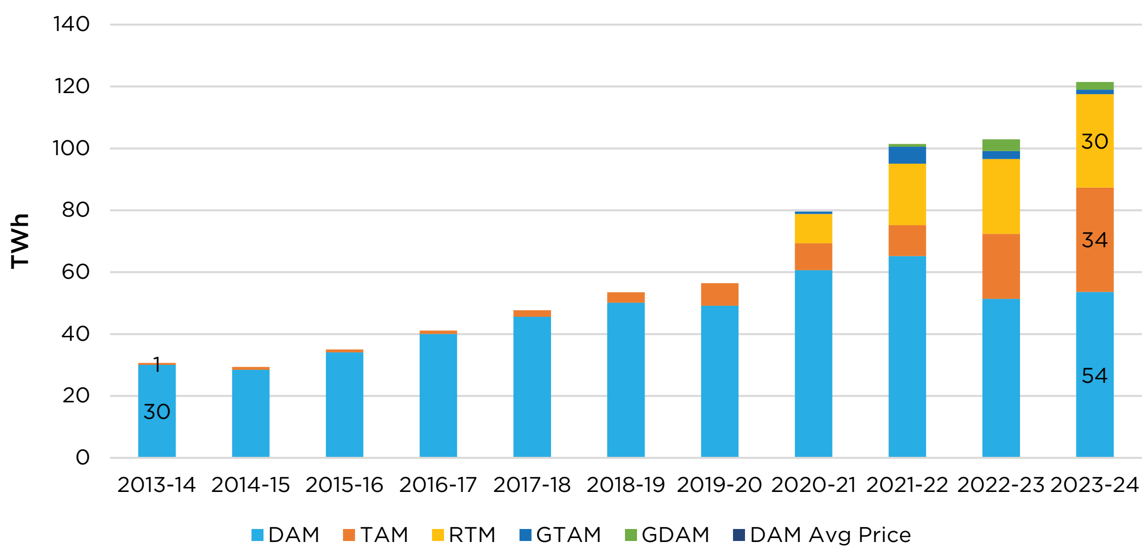


Figure 1.14: Overview of power traded on exchanges[5]

5 Day Ahead Market; TAM – Term Ahead Market; RTM – Real Time Market; GTAM- Green Term Ahead Market; GDAM – Green Day Ahead Market; RRAS - Reserves Regulation Ancillary Services;

HP-DAM - High Price Day Ahead Market

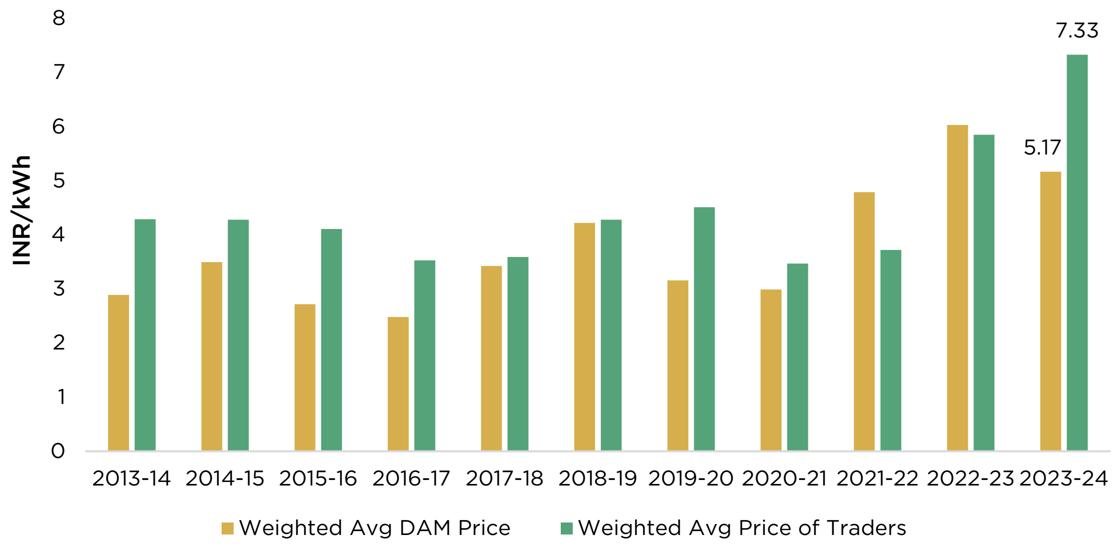


Figure 1.15: Average price of electricity (exchange vs bilateral trading)

This detailed review of India's power sector expansion shows how developments in generation, transmission and market design have created the physical backbone for a more reliable and diversified system. The next chapter turns to the evolving policy and regulatory architecture and examines how successive policies, regulations and programmes have shaped and will continue to shape the way this infrastructure is planned, operated and supports the transition to a low-carbon power system.

2

CURRENT POLICY LANDSCAPE

Current Policy Landscape

2

Within this evolving framework (discussed in the previous chapter), the Indian power sector is transforming to meet the twin objectives of meeting growing electricity demand reliably and progressively shifting the generation mix towards cleaner sources. India is working towards reducing carbon emissions from the power sector as part of its broader development strategy, recognising that electricity is both a major source of GHG emissions and a key lever for economy-wide mitigation. In pursuit of these objectives, the government has introduced several policies and programmes to scale RE, reduce dependence on coal and promote energy efficiency. These efforts include modernising the grid and power markets, developing energy storage solutions and encouraging the use of green hydrogen. At the same time, policies are being designed to ensure that this transition is fair, affordable, and benefits all sections of society. This chapter discusses the major policies and initiatives India has adopted to move towards a cleaner power sector.

Figure 2.1 presents a year-wise overview of key policies shaping India's power sector since 2003, highlighting the evolution from access and distribution reforms to large-scale renewable energy deployment, grid modernisation, market reforms, energy storage, and emerging technologies such as green hydrogen. Building on this evolution, the following sections discuss key policies and initiatives in detail, grouped by their focus areas, and examine their role in facilitating India's transition towards a cleaner, more reliable, and resilient power sector.

2.1 POLICY INITIATIVES FOR LOW-CARBON TRANSITION OF POWER SECTOR

India has implemented significant initiatives to boost electricity generation and ensure clean and reliable power. The Electricity Act of 2003 paved the way for private participation and encouraged competition in the power sector, from generation to distribution. This was complemented by the National Electricity Policy (NEP), providing a roadmap for affordable electricity access and sustainable development. The National Electricity Tariff Policy (2006, amended in 2016) further promoted renewable energy integration by requiring distribution utilities to source a portion of their power from renewable sources.

One of the most significant outcomes of India's renewable energy policies has been the drastic reduction in solar tariff, making clean energy economically competitive with conventional sources. Solar tariff in India has fallen from about INR 12.16/kWh in the early 2010s to around INR 2-3/kWh following policies such as the National Solar Mission (NSM) and competitive reverse auction (Economic Times, 2020), representing a decline of 70-80%. In case of wind, reverse auctions commenced in 2017, and since then, the tariffs have seen a consistent trend revolving around INR 3-4/kWh.

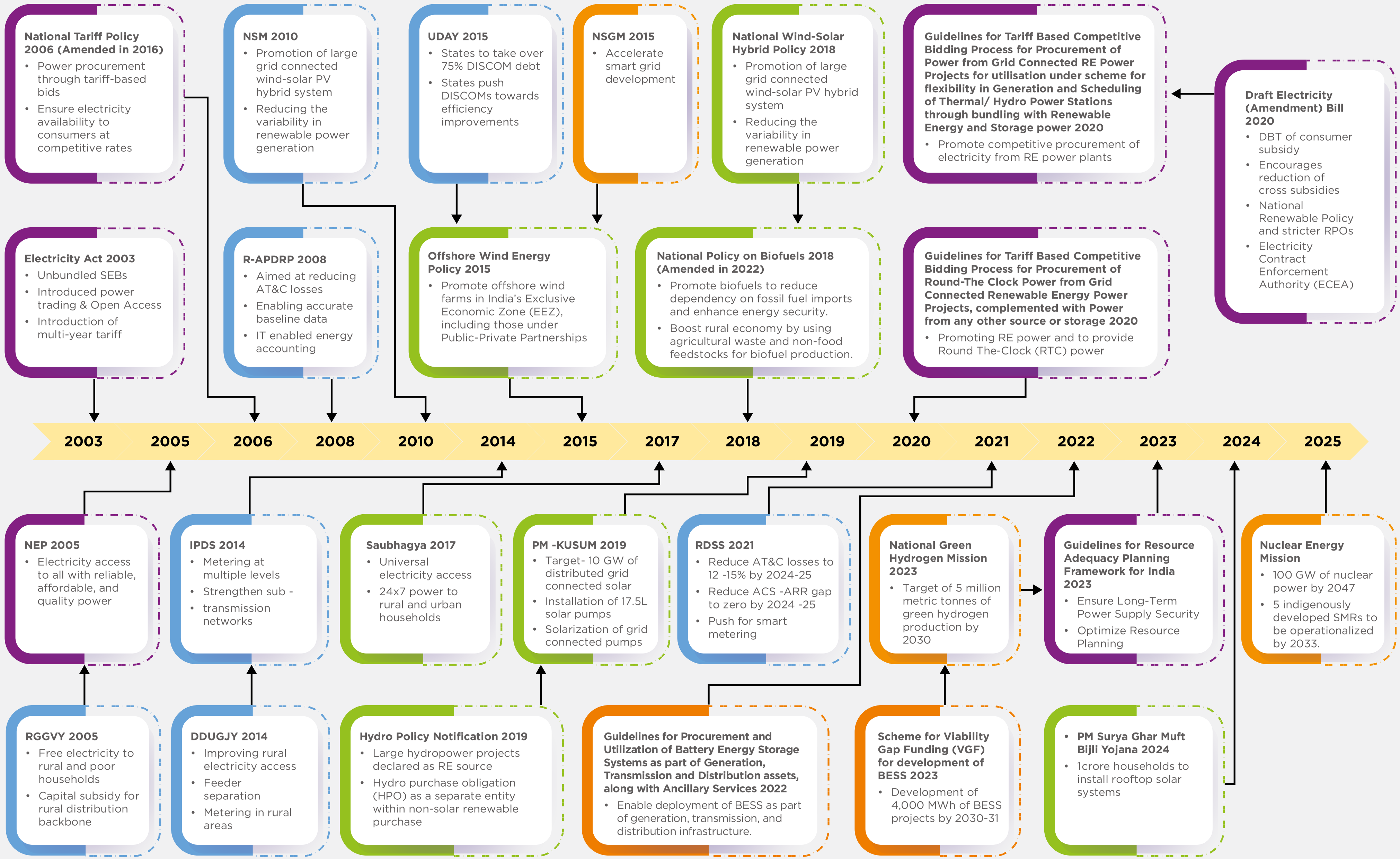


Figure 2.1: Key policies and schemes in India's power sector

NEP: National Electricity Policy; IPDS: Integrated Power Development Scheme; RGGVY: Rajiv Gandhi Grameen Vidyutikaran Yojana; DDUGJY: Deen Dayal Upadhyaya Gram Jyoti Yojana; Saubhagya: Sahaj Bijli Har Ghar Yojana; PM-KUSUM: Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan; RDSS: Revamped Distribution Sector Scheme; NSM: National Solar Mission; UDAY: Ujwal DISCOM Assurance Yojana; NSGM: National Smart Grid Mission; R-APDRP: Restructured-Accelerated Power Development and Reforms Programme

The transition from Feed-in Tariffs (FiTs) to standard guidelines for tariff-based competitive bidding played a crucial role in this cost reduction, along with declining equipment prices and lower financing costs. A major step towards clean energy adoption in the agriculture sector was the launch of Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan (PM-KUSUM) Scheme in 2019. The scheme aims to de-dieselise the farming operations, expand RE deployment, and enhance farmers' incomes. This scheme targets the addition of 34,800 MW of solar capacity by 2026 and with financial support of INR 34,422 crore. As of December 2025, the scheme has recorded progress as summarised in Table 2.1 (MNRE).

Table 2.1: PM-KUSUM achievements as on 30.12.2025

Component A		Component B		Component C			
Solar capacity (MW)		Standalone Pumps (Nos.)		Individual Pump Solar-IPS (Nos)		Feeder Level Solar - FLS (Nos.)	
Sanctioned	Installed	Sanctioned	Installed	Sanctioned	Solarised	Sanctioned	Solarised
10,000	720.91	13,15,190	9,75,277	55,392	11,781	35,27,492	11,89,787

Complementing these supply and agriculture-focused interventions, the PM Surya Ghar: Muft Bijli Yojana (2024) was launched to accelerate residential rooftop solar adoption (MNRE). The scheme aims to provide subsidy support to empower one crore households by March 2027. It seeks to make RE more affordable and accessible through the addition of 30 GW of rooftop solar capacity in the residential sector. It is estimated that the scheme will reduce approximately 720 million tonnes of carbon emissions over the 25-year lifetime of these rooftop systems (PIB, 2024). As of December 3, 2024, the programme has seen significant participation, with 1.45 crore registrations and 26.38 lakh applications recorded on the National Portal.

Further, the Model Solar Village component under this scheme focuses on establishing one Model Solar Village per district throughout India, supporting rural energy self-reliance and setting India on a path toward a greener and more sustainable future.

Reinforcing the deployment-focused Renewable Purchase Obligation (RPO) scheme, Renewable Consumption Obligation (RCO) has also been notified, placing onus on major consumers rather than just distribution utilities. RCO mandates DISCOMs, open access consumers, and captive generators to obtain a defined share of their electricity from renewable sources. RCO also includes a specified quantum of consumption from Decentralised Renewable Energy Sources. Under these, targets are specified for each year, with values increasing incrementally through 2030. Supporting these mandates, Renewable Energy Certificates (RECs) are issued to verify and trade RE generation, allowing obligated entities to meet their targets or to reduce carbon footprints voluntarily. Together, these frameworks provide market-based instruments to complement PM-KUSUM and PM Surya Ghar schemes and advance India's climate objectives.

In addition to the above, several other national-level policies and initiatives have been introduced by the Government of India to promote and accelerate RE capacity addition in the country and support the low-carbon transition across different segments:

- **The National Offshore Wind Energy Policy (2016)** focuses on exploring and developing offshore wind energy potential within India's Exclusive Economic Zone. It lays down a framework for resource assessment, leasing of offshore areas, and project development, contributing to India's target of expanding its non-fossil fuel capacity (MNRE, 2015).

- **The National Wind-Solar Hybrid Policy (2018)** aims to promote large-scale hybrid renewable energy projects by combining wind and solar technologies at a single site. This helps in better utilisation of land and transmission infrastructure while ensuring a more stable power supply (MNRE, 2018).
- **The National Policy on Biofuels (2018)** promotes the use of biofuels like ethanol, biodiesel, and advanced biofuels to reduce dependence on fossil fuels and cut greenhouse gas emissions. It sets ambitious targets for blending ethanol with petrol and encourages the production of biofuels from various feedstocks, including agricultural waste and used cooking oil (MoPNG, 2018).
- **National Programme on Advanced Chemistry Cell (ACC) Battery Storage (2021)** was launched to support domestic manufacturing and reduce reliance on imports. With a Production Linked Incentive (PLI) outlay of INR 18,100 crore, the scheme aims to establish a manufacturing capacity of 50 GWh of ACCs and an additional 5 GWh for niche ACC technologies. The objective is to encourage private sector investment in large-scale battery manufacturing for electric vehicles, grid storage, and consumer electronics. The scheme mandates a minimum 60% domestic value addition within five years and requires firms to set up an integrated facility, from cell to pack (Ministry of Heavy Industries).
- **National programme on High Efficiency Solar PV Modules (2022)** aims to build an ecosystem for manufacturing of high-efficiency solar PV modules in India, and thus reduce import dependence on imported solar equipment. Under Tranche-II of the scheme, with an outlay of INR 19,500 crore, the programme targets the establishment of around 65 GW per annum of fully and partially integrated solar PV module manufacturing capacity. By offering performance-based incentives over five years, the PLI scheme is expected to encourage vertically integrated, gigawatt-scale manufacturing, boost domestic production, strengthen energy security, and support India's target of 500 GW of non-fossil fuel capacity by 2030 (MNRE).
- **Scheme for setting up Solar Parks and Ultra Mega Solar Power Projects (2023)** is being implemented to provide land and transmission infrastructure to RE developers for the installation of RE projects at a large scale. Under this scheme, the GoI has sanctioned 55 Solar Parks with an aggregate capacity of over 39 GW across 13 States with implementation timelines extending until 31 March 2029.
- **National Repowering and Life Extension Policy for Wind Power Projects (2023)** aims to boost RE by replacing old, inefficient wind turbines with modern, higher-capacity machines or by refurbishing existing turbines to extend their operating life. This will maximise energy generation per unit of land area, with a repowering potential of 25,406 MW identified for turbines below 2 MW (MNRE).
- **The National Green Hydrogen Mission (2023)** is a recent and strategic initiative to promote the production and use of green hydrogen as a clean fuel alternative, especially in sectors like refinery, fertilisers, steel, and heavy-duty transport. The mission targets the development of 5 Mt (million tonnes) of green hydrogen production capacity annually by 2030, supported by policy incentives, R&D, and international cooperation (MNRE).

- **National Framework for promoting & developing Energy Storage Systems (ESS) (2023)** will encourage and create an ecosystem for development of Energy Storage based on requirements and financial feasibility. ESS facilitates transition from fossil fuel to RE by making RE dispatchable and available round the clock (MoP, 2023).
- **Viability Gap Funding for development of Battery Energy Storage Systems (2023):** With an initial outlay of INR 9,400 crore, including a budgetary support of INR 3,760 crore, the scheme envisages the development of 4,000 MWh of Battery Energy Storage System (BESS) projects by 2030-31, with financial support of up to 40% of the capital cost provided as budgetary assistance in the form of VGF.
- **New Solar Power Scheme (for Tribal and PVTG Habitations/Villages) under PM JANMAN and PM JUGA (2024)** aims to provide reliable and clean electricity access to tribal and Particularly Vulnerable Tribal Group (PVTG) habitations and villages. It focuses on deploying decentralised solar solutions, including off-grid and mini-grid systems, to address last-mile energy access challenges. This initiative seeks to reduce dependence on diesel, support local livelihoods, and enable socio-economic development in remote and underserved areas, aligning with India's clean energy and inclusive growth objectives (MNRE, 2024).
- **Viability Gap Funding (VGF) Scheme for Offshore Wind Energy Projects (2024)** is a major step towards the implementation of the National Offshore Wind Energy Policy, notified in 2015. With an outlay of INR 7,453 crore, the scheme supports 1 GW of offshore wind projects off the coasts of Gujarat and Tamil Nadu and port upgrades to reduce power costs and make such projects viable for DISCOM procurement (MNRE, 2024).

In addition to these initiatives, a Nuclear Energy Mission was announced in the Union Budget 2025-26, as part of India's clean energy agenda and the vision of Viksit Bharat. The mission sets an ambitious target of 100 GW nuclear power capacity by 2047, making it a key part of India's future energy mix. This will help reduce dependence on fossil fuels and ensure reliable, low-carbon electricity. To facilitate this expansion, the Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Act, 2025, has been enacted. This Act allows significant private participation in the nuclear sector under regulatory oversight. In addition to this, Mission focuses on the research and development of Small Modular Reactors (SMRs) with a financial outlay of INR 20,000 crore, targeting the operationalisation of at least five indigenously designed and operational SMRs by 2033 (PIB, 2025). These smaller, advanced reactors are safer, easier to build, and can be used in industries or remote areas.

2.2 POLICY INITIATIVES FOR INFRASTRUCTURE DEVELOPMENT AND GRID MODERNISATION

Modernising the power sector's infrastructure is critical to accommodate the growing share of RE and ensure a reliable, efficient, and resilient electricity supply. India has launched several flagship programmes to upgrade its transmission and distribution networks and make the grid smarter and more responsive to evolving energy needs.

One of the key initiatives in this regard is the National Smart Grid Mission (NSGM), launched in 2015. The mission focuses on planning and implementing smart grid projects in India to modernise the electricity network. It promotes the use of advanced technologies such as smart meters, automated demand response, and real-time grid monitoring systems to make the grid more responsive, resilient, and consumer-friendly.

Under NSGM, pilot projects have been implemented across various states to demonstrate smart metering, outage management, and integration of distributed energy resources. The mission also supports capacity building, policy formulation, and collaboration between public utilities and technology providers to foster innovation in grid management.

Complementing this, the Green Energy Corridor (GEC) project is a major initiative to strengthen the transmission infrastructure required to evacuate power from RE-rich states to load centres across the country. Launched in two phases, the project covers both intra-state and inter-state transmission systems (Ministry of Power, 2025). The GEC ensures grid stability by deploying technologies like reactive power management and battery storage, paving the way for large-scale RE integration.

In addition to these flagship programmes, several policy and planning measures have been undertaken to further strengthen transmission infrastructure and facilitate renewable energy integration. Inter-State Transmission System (ISTS) charges have been waived for the inter-state sale of solar and wind power projects commissioned up to 30 June 2025, for green hydrogen projects till December 2030, and for offshore wind projects till December 2032, helping in improving the commercial viability of these projects. Further, a comprehensive transmission expansion plan has been prepared up to 2030 to ensure the timely augmentation of network capacity and grid reliability.

To address the challenges in the distribution segment, Revamped Distribution Sector Scheme (RDSS) was launched in 2021 (Ministry of Power, 2024). The scheme focuses on improving the operational efficiency and financial sustainability of DISCOMs through infrastructure upgrades, feeder separation, smart metering, and reducing AT&C losses to 12-15%. As of March 17, 2025, projects worth over INR 2.78 lakh crore have been sanctioned for 32 States/UTs for loss reduction and smart metering works, with early results showing improved reliability and consumer satisfaction in several states (Ministry of Power).

Carbon Credit Trading Scheme (CCTS): CCTS is a market-based mechanism that places a price on carbon to encourage a reduction in greenhouse gas (GHG) emissions. The scheme consists of two main components: a compliance mechanism for the obligated entities to meet mandatory emission targets, and an offset mechanism that allows voluntary participation by businesses and institutions aiming to lower their carbon footprint. Initially, it started with nine energy-intensive sectors, including steel, cement, aluminium, refining, fertilisers, and petrochemicals, by assigning emission intensity targets, measured in CO_2 equivalent per unit of output. Companies that emit less than their assigned target can earn Carbon Credit Certificates (CCCs), which can be traded with those exceeding their limits, encouraging low-carbon production. The Bureau of Energy Efficiency (BEE) is tasked with implementing this system under the amended Energy Conservation Act, 2022.

Together, these infrastructure initiatives are transforming India's power system into a future-ready grid which will be capable of handling higher renewable penetration, reducing losses, and delivering quality power to all.

2.3 STATE-LEVEL POLICIES AND INITIATIVES

While national-level policies have played a foundational role in India's renewable energy transition, several states have taken proactive steps in formulating their own targeted policies to accelerate clean energy deployment. These state-level policies are tailored to local resource availability, investor needs, and socio-economic priorities, making them key enablers of India's clean energy journey.

Gujarat has emerged as a frontrunner in RE, with several forward-looking policies. The Gujarat RE Policy (2023) aims to harness the state's vast RE potential and includes provisions for solar parks, distributed solar, offshore wind, wind-solar hybrid and repowering of old RE projects with investments of around INR 5 lakh crore (Government of Gujarat, 2023). To address urban waste challenges, the Gujarat Waste-to-Energy Policy (2022) promotes the generation of energy from solid and liquid waste, offering financial incentives and support for project developers (Government of Gujarat, 2023). Gujarat also implemented the Surya Gujarat Scheme, aimed at promoting rooftop solar (RTS) in the residential sector with subsidies and simplified procedures.

Rajasthan, being rich in solar and wind resources, has announced ambitious targets under the Rajasthan Integrated Clean Energy Policy (2024). The policy aims to develop 125 GW of RE capacity by 2030, including 90 GW solar, 25 GW wind & hybrid, and 10 GW from hydro and storage systems (Government of Rajasthan, 2024). It includes a holistic framework designed to consolidate various clean energy segments, including solar, wind, biomass, waste-to-energy, and green hydrogen under one comprehensive umbrella. The policy aims to maximise resource utilisation, promote integrated project development, and encourage sectoral convergence between energy generation, transmission, and storage.

Karnataka has consistently ranked among the top states for installed RE capacity. Its Renewable Energy Policy (2022-2027) promotes a diverse energy mix including wind, solar, small hydro, and biomass, to achieve an additional 10 GW of installed RE capacity with or without energy storage systems in the State, including up to 1 GW of RTS PV projects. The policy also emphasises ease of doing business, land availability, and grid connectivity (Government of Karnataka, 2022).

Andhra Pradesh has launched the Andhra Pradesh Integrated Clean Energy Policy (2024) aimed at developing about 160 GW of renewable and pumped storage capacity, positioning the state as a clean energy hub. The policy focuses on decarbonisation, decentralisation, digitalisation, and democratisation of the power sector, promoting solar, wind, PSP, energy storage, and green hydrogen. It also supports distributed generation through rooftop solar and solar pumps, encourages RE exports, and enables EV charging infrastructure. Andhra Pradesh aspires to become the storage capital and a leader in green hydrogen production, while boosting investments, local manufacturing, and job creation. The policy also envisions setting up a University for Green Energy & Circular Economy to drive research, skilling, and entrepreneurship. Earlier initiatives like the Wind-Solar Hybrid Policy (2018), PSP Promotion Policy (2022), and RE Export Policy (2020) continue to complement the state's clean energy growth (Andhra Pradesh Electricity Regulatory Commission, 2024).

Madhya Pradesh launched its Renewable Energy Policy (2022) with a focus on scaling up clean energy deployment and manufacturing. The state targets an investment of INR 15,000 crore by 2024 and INR 50,000 crore by 2027 in the RE generation sector, along with an investment of INR 4,000 crore by 2024 and INR 10,000 crore by 2027 in the RE equipment manufacturing sector. The policy sets progressive targets to increase the share of renewables in the state's energy mix, aiming for 20% by FY 2024, 30% by FY 2027, and 50% by FY 2030. Madhya Pradesh is already known for innovative projects like the Rewa Ultra Mega Solar Park, which set benchmarks in cost-effective solar power and public-private partnerships (Government of Madhya Pradesh, 2022).

Overall, these policies reflect India's commitment to reducing its reliance on fossil fuels, fostering renewable energy integration, and ensuring inclusive and reliable energy access. Additional initiatives supporting the clean energy transition in the power sector, not explicitly discussed here, are summarised in Annexure A.

3

METHODOLOGY FOR POWER SECTOR MODELLING

Methodology for Power Sector Modelling

3

As the country advances towards becoming Viksit Bharat by 2047, the electricity system will play a central role in driving economic growth, industrial competitiveness, improved living standards, and the transition to a low-carbon economy. Rapid electrification across end-use sectors, expanding renewable energy deployment, and the growing role of storage and flexibility solutions are reshaping the power system. In this context, robust power sector modelling is essential to assess future demand trajectories, capacity expansion pathways, emissions outcomes, and implications for investment costs, land requirements, and water use under different scenarios. This chapter presents the methodological framework and scenario analysis used to evaluate India's future electricity landscape, providing an integrated and consistent basis for assessing pathways towards a secure, affordable, and sustainable power system.

3.1 METHODOLOGY DESCRIPTION

The analysis of the power sector in this study is based on a comprehensive, integrated modelling framework that captures economy-wide demand dynamics and translates them into detailed capacity and generation outcomes. This integrated framework employs soft-linking of three modelling components: 1) demand assessment tools that project activity demand across different energy end-use sectors; 2) an energy system model that estimates final energy consumption for each end-use sector; and 3) detailed power sector models that translate electricity demand into capacity expansion and generation outcomes.

Activity demand in physical units for each energy sector, such as Transport, Industry, Buildings (Residential & Commercial), Cooking, and Agriculture, is first projected using a range of approaches, including historical analysis, regression, elasticity analysis and per capita saturation trends in major economies. Detailed demand projections can be found in the respective sectoral reports.

These estimated demands serve as input to NITI Aayog's in-house Energy Models (IESS[6] and TIMES[7]). Based on assumptions regarding technology mix, specific energy consumption, efficiency, appliance use, penetration of clean technologies/fuels, and relevant policy considerations, these models estimate the final energy demand and fuel mix for each sector. The resulting fuel mix is then used to derive sector-wise electricity consumption, capturing both industrial captive generation and utility-supplied electricity requirements.

These sectoral consumptions are aggregated to obtain total electricity demand at the consumer level. The resulting electricity demand is then provided as input to detailed Power Sector

6 IESS – India Energy Security Scenario

7 The Integrated MARKAL-EFOM System

Models developed by NITI Aayog (TIMES Power Model) and the model being used by Central Electricity Authority (ORDENA), see Figure 3.1. Detailed power sector modelling is carried out on these platforms, considering the same electricity demand, and the results are aligned to ensure consistency in both Capacity and Generation Mix.

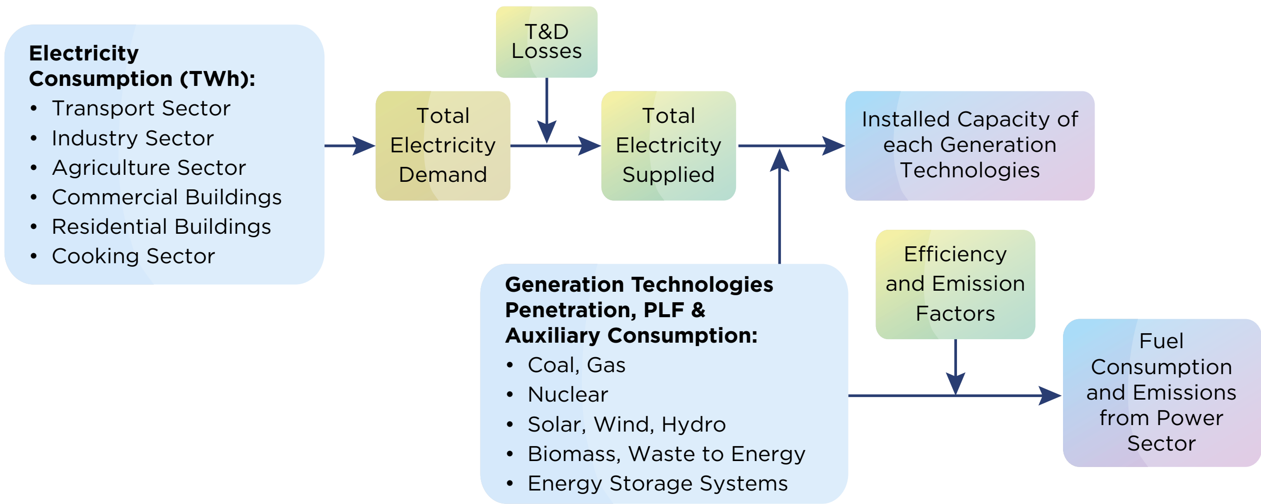


Figure 3.1: Methodology for power sector modelling

Since not all generated electricity reaches end users due to transmission and distribution (T&D) losses, these losses are added to the total demand to determine the total electricity that must be supplied by the power system.

The required electricity supply is then met through an optimisation framework that allocates generation across available technologies subject to installed capacity and system constraints. The model determines electricity generation from technologies such as coal, gas, nuclear, solar, wind, hydro, and biomass by minimising total system cost, while accounting for technology-specific costs, availability, plant load factors (capacity utilisation), auxiliary consumption, and policy constraints. Once generation by each technology is determined, technology-specific efficiency and emission factors are applied to estimate corresponding fuel consumption and emissions. The final outputs of the model include the capacity mix, generation mix, total fuel use and emissions from the power sector, which inform energy planning, policy analysis, and climate impact assessments.

3.2 SCENARIO DESCRIPTION

For exploring India's net-zero pathways, NITI Aayog has developed its own integrated energy sector model that maps out future energy demand, fuel consumption, and emissions across the entire energy economy. The model covers all energy-economy sectors such as Agriculture, Buildings, Transport, Industry, and Power, to provide a holistic view of India's energy transition. Using this framework, two key scenarios have been developed: the Current Policy Scenario and the Net Zero Scenario. These scenarios were developed through extensive consultations with inter-ministerial working groups and sectoral experts.

- **Current Policy Scenario (CPS):** This scenario represents a level of effort that is realistically achievable based on historical trends and recent progress. It assumes that current policies (as of 2023) and past trends will continue, leading to a slow adoption of low-carbon technologies in each sector.
- **Net Zero Scenario (NZS):** This 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 technology deployment and significant behavioural and structural shifts across sectors. Key strategies include rapid electrification of end-use sectors, substantial gains in energy efficiency, adoption of circular economy practices, and high penetration of renewable and clean energy technologies.

  The subsequent sections first present the detailed methodology for sectoral electricity demand estimation adopted within the integrated energy sector model, followed by an in-depth discussion of the capacity expansion planning methodology and underlying assumptions that constitute the power sector modelling framework.

3.3 ELECTRICITY DEMAND PROJECTIONS: METHODOLOGY AND KEY ASSUMPTIONS

There could be multiple approaches to estimating future electricity demand, with the two most used being the top-down and bottom-up methodologies. A top-down approach projects future electricity demand based on macroeconomic and system-level drivers, and then, if needed, disaggregates into sectors, regions, or end uses. While the bottom-up approach is a method where total electricity demand is built up from detailed end-use, sectoral, and technology-level consumption, rather than starting from aggregate economic indicators.

The Electric Power Survey (EPS) conducted by the Central Electricity Authority (CEA) uses the Partial End Use Method (PEUM), which is a bottom-up approach that combines time series analysis and end-use methods to forecast electricity demand at the consumer category level. This method works out demand projections by grouping end-users under various categories of electricity consumers, such as Domestic, Commercial, Public Lighting, Public Water Works, Irrigation, Industrial, Railway Traction, and Bulk (Non-Industrial HT) Supply. The time series component derives growth indicators by giving higher weightage to recent trends. Apart from general growth trends assessed from the past data, the likely impacts of various emerging aspects and governmental initiatives/ policies such as Energy Efficiency Measures, penetration of Electric Vehicles, Solar Roof-top, National Hydrogen Mission, PM-KUSUM Yojna, etc., have also been factored in while assessing the electricity demand in future.

This study also adopts a bottom-up approach, building electricity demand projections from the ground up by assessing the expected consumption within individual sectors, namely agriculture, buildings (including cooking), transport and industry. A bottom-up, technology-rich, partial equilibrium, optimisation tool is employed to develop an integrated energy sector model. In this framework, the end-user demand for each sector is driven by the macroeconomic parameters: GDP, urbanisation, and population. To meet the projected demand, the study determines an optimal energy mix separately for each scenario based on different choices/assumptions such as energy efficiency improvements, electrification trends, and emerging demand drivers such as electric vehicles, data centres, and green hydrogen production. Detailed information is available in the sectoral reports. The total electricity demand is then derived by aggregating the electricity consumption across all sectors.

3.3.1 Agriculture Sector

The agriculture sector, especially water pumping operations in FY 2024 accounted for nearly 18% of the total electricity consumption, with overall electricity demand in agriculture growing at a compound annual growth rate (CAGR) of 5.24% between 2018-19 and 2023-24 (CEA, 2025). Several factors influence electricity use in agriculture, including groundwater depletion, shifting crop patterns, pump set efficiency, and the growing penetration of electric vehicles in tractor/ tiller sales. For a detailed analysis of the agricultural sector energy transition, Working Group Report on Agriculture Sector, Vol. 6 can be referred to. However, the broad assumptions that are driving the electricity demand growth are listed here (see Table 3.1):

Table 3.1: Assumptions for projecting electricity consumption in Agriculture Sector

Levers	Current Policy Scenario	Net Zero Scenario
Diesel pumps (Currently, 28%)	Phased out by 2040	Phased out by 2035
Electric pump efficiency (Currently 36%)	Improves to 40% by 2070	Improves to 50% by 2070
Share of electric (grid) pumps (Currently, 70%)	60% by 2070	40% by 2070
Share of electric tractors and tillers	50% (2050) and 85% (2070)	65% (2050) and 100% (2070)

3.3.2 Transport Sector

The transport sector is one of the key energy-consuming sectors in the country. It is responsible for consuming the largest amount of petroleum products (petrol and diesel mainly). In 2020, road transport contributed to 9.13% of India's total GHG emissions (MoEFCC, 2024). In FY 2023-24, the transport sector accounted for 2.20% of India's total electricity demand (CEA, 2025), mainly due to the load of railways and metros.

As seen in the recent trends in the transport sector globally, India’s market is also signalling the beginning of a new era of mobility. The central and state governments have introduced various policies and initiatives to accelerate the adoption of electric vehicles.

Transport sector demand is measured in billion passenger-kilometres (bpkms) for passenger transport and billion tonne-kilometres (btkms) for freight transport. Passenger transport is categorised into road, metro, rail, and air, while freight transport is divided into road, rail, air, water, and pipeline modes. In the Net Zero Scenario, total transport demand in both passenger-kilometres (btkms) and tonne-kilometres (btkms) is lower than in the Current Policy Scenario, primarily due to the consideration of transit-oriented development planning, which reduces overall travel demand.

The electricity demand in the transport sector will be driven by changes in modal shift, share of public/private transport modes within passenger road and electrification share in passenger and freight segments. For a detailed analysis of the transport sector energy transition, Working Group Report on Transport Sector, Vol. 3 can be referred to. However, the broad assumptions that are driving the electricity demand growth in this sector are listed here (see Table 3.2):

Table 3.2: Assumptions for projecting electricity consumption in the Transport Sector

Levers	2024	Current Policy Scenario		Net Zero Scenario	
		2050	2070	2050	2070
Modal Share of Rail					
Passenger	17%	19%	20%	22%	25%
Freight	22%	24%	25%	27%	30%
Modal Share of Metro					
Metro	1%	2%	2%	2%	3%
EV Penetration in New Sales					
2W	6%	100%	100%	100%	100%
3W	57%	90%	90%	100%	100%
4W-Car	3%	60%	80%	70%	85%
4W-Taxi		60%	80%	95%	95%
Bus	3.50%	80%	80%	90%	90%
Vehicles payload upto 3.5 tonnes	1%	60%	80%	90%	95%
Vehicles payload from 3.5-12 tonnes	-	15%	60%	50%	95%
Vehicles payload above 12 tonnes	0.10%	4%	50%	25%	80%

3.3.3 Building Sector

Energy demand in the building sector includes demand in Commercial Buildings, Residential Buildings, and the Cooking Sector. In 2023-24, the residential sector accounted for nearly 23.96% of the country's electricity consumption, while the commercial sector contributed around 8.35% (CEA, 2025). The cooking sector primarily relies on traditional biomass in rural areas, as well as LPG and PNG in urban and semi-urban areas.

Between FY 2018-19 and FY 2023-24, electricity consumption in the residential and commercial sectors grew at a compound annual growth rate (CAGR) of 5.1% and 5.5%, respectively (CEA, 2025). This growth is primarily driven by rising population and rapid urbanisation. In the Commercial Sector, the expansion of built floor space and the increasing share of airconditioned buildings are the key drivers of rising electricity demand. In the residential sector, increasing ownership and use of appliances such as air conditioners, refrigerators, and electric water or space heaters, reflecting an improving standard of living, contributes to electricity consumption. In the Cooking Sector, the gradual shift towards electric cooking is expected to contribute to electricity consumption. For a detailed analysis of the building sector's energy transition, Working Group Report on Building Sector, Vol. 5 can be referred to. While energy use in residential and commercial buildings is predominantly electric, the difference across scenarios stems from changes in efficiency improvement considered and the penetration rate of smart buildings. Table 3.3 summarises the key differences across sectors and two scenarios.

Table 3.3: Assumptions for projecting electricity consumption in the Building Sector

Levers	Current Policy Scenario	Net Zero Scenario
Penetration of smart buildings in commercial (<1% current)	Improves to 35%	Improves to 60%
Appliance efficiency standards for Residential buildings	Average efficiency standards to reach India's best by 2050 and global best by 2070	Average efficiency standards to reach global best by 2050
Electrification share of cooking (<1% current)	Improves to 30% by 2070	Improves to 60% by 2070

3.3.4 Industry Sector

The energy transition in the industrial sector will be driven by efficiency improvements, demand electrification, adoption of cleaner technologies, increased use of clean fuels such as green hydrogen and biofuels, and enhanced material circularity. In 2020, the industrial sector accounted for 24.4% (excluding emissions from electricity use) of the country's total greenhouse gas (GHG) emissions (MoEFCC, 2024). Also, the sector accounted for 41.6% of total electricity consumption in 2023-24 (CEA, 2025). Of this, about 70.26% was sourced from the grid, while the remaining 29.74% came from captive power generation (CEA, 2025). Electricity consumption in the industrial sector grew at a CAGR of 4.3% over the last five years (FY 2018–19 to FY 2023–24) (CEA, 2025). Since electricity is one of the most efficient forms of energy, the industrial sector is likely to witness a continued increase in electricity consumption as it transitions toward cleaner and more efficient energy systems. With improving grid reliability and the Government of India's increasing focus on decarbonising grid electricity, there is a strong possibility of a shift from captive power to grid-based electricity.

For energy demand estimation, the industrial sector is classified into nine sub-sectors: steel, cement, aluminium, fertilisers, textiles, paper & pulp, chlor-alkali, chemicals, and other industries. This classification is based on segregating energy-intensive industries, designated under the Perform, Achieve and Trade (PAT) scheme, while grouping all other industries under the single category of "other industries." For a detailed analysis of the industry sector's energy transition, Working Group Report on Industry Sector, Vol. 4 can be referred to. However, the key assumptions driving the electricity demand growth in this sector are summarised in Table 3.4.

Table 3.4: Assumptions for projecting electricity consumption in the Industry Sector

Levers	Current Policy Scenario (2070)	Net Zero Scenario (2070)
Industry Sector Electrification: 16%	29%	55%
Share of Captive (in selected sectors)		
Steel: 63%	50%	35%
Cement: 58%	50%	20%
Aluminium: 88%	70%	40%
Share of Scrap (in selected sectors)		
Steel: 20%	Remains same at the current level	Increases to 40%
Aluminium: 30%	Remains same at the current level	Increases to 40%

With these assumptions, Industrial sector electrification is projected to reach about 29% under the Current Policy Scenario and 55% under the Net Zero Scenario by 2070, compared to 16% at present.

3.3.5 Electricity Required for Green Hydrogen

Hydrogen is emerging as a key pillar in India's transition to a low-carbon economy. Recognised for its versatility and clean-burning properties, hydrogen can play a crucial role in decarbonising hard-to-abate sectors such as refining, fertilisers, steel, and heavy transport.

India is among the largest producers and consumers of grey hydrogen, primarily used in refineries, fertiliser and ammonia production. However, under the National Green Hydrogen Mission (NGHM), the focus is shifting toward green hydrogen, produced using renewable electricity, biomass and water. Under this mission, the country aims to produce 5 million metric tonnes (MMT) of green hydrogen annually by 2030. With this ambitious goal, India aims to position itself as a global hub for green hydrogen production and exports. The detailed consumption trajectories of green hydrogen in industrial and transport sectors can be found in their respective Working Group Reports. A broad assumption for green hydrogen production growth is summarised below:

Current Policy Scenario: In this Scenario, the high cost of green hydrogen compared to grey hydrogen makes achieving the 5 million tonnes production target by 2030 unlikely. Most of the hydrogen produced during this period is expected to be exported, with limited domestic adoption until production costs decline after 2035. By 2050, green hydrogen production is projected to reach around 8.5 million tonnes, primarily serving refineries, fertiliser production, steel manufacturing, and export markets. However, as costs continue to fall, production is expected to increase significantly, reaching approximately 24 million tonnes annually by 2070.

Net Zero Scenario: In this scenario, India is closer to achieving its Green Hydrogen Mission target of 5 million tonne per annum production capacity, although with a modest delay of 1-2 years. In this scenario, green hydrogen is assumed to be used across fertiliser, refinery, steel and transport (buses, HCVs). Its role in producing green methanol and ammonia for the shipping sector is also explored. Under this scenario, India is assumed to capture around 5% of the IEA-projected global low-emission hydrogen production of 520 million tonne per year by 2050 (IEA, 2021), implying domestic green hydrogen production of roughly 26 million tonnes by 2050, rising to nearly 50 million tonnes by 2070.

3.3.6 Miscellaneous and Data Centres

The miscellaneous category includes electricity consumption for public lighting, public water works and sewage pumping, and other miscellaneous uses. It accounted for 6.03% of India's total electricity consumption in 2023-24. Within this category, the share of electricity use is approximately 10% for public lighting, 34.7% for public water works & sewage pumping, and 55.3% for other miscellaneous uses (CEA, 2025).

As India continues to urbanise and expand its infrastructure, electricity demand from these sectors is expected to increase significantly.

Further, in the case of data centres, the estimated power load in 2024 was around 1.4 GW (Statista, 2024). Data centres form the backbone of the digital economy, supporting a wide range of services including cloud computing, social media, e-commerce, AI, and government platforms. With the rapid digitalisation of the country, driven by initiatives such as Digital India, and the growth of 5G and AI applications, the demand for high-performance, always-on data infrastructure is accelerating.

It is projected that the electricity load from data centres will reach approximately 45 GW by 2050 and 80 GW by 2070. For a detailed analysis, the Working Group Report on Building Sector, Vol. 5 can be referred to.

3.4 CAPACITY EXPANSION PLANNING: METHODOLOGY AND KEY ASSUMPTIONS

For power sector capacity expansion planning, ORDENA[8] and TIMES[9] are leveraged to assess the impact of different policy choices, technological developments, and economic assumptions on the energy system.

3.4.1 Model Description

Models used for power sector capacity expansion planning are technology-rich, bottom-up models with high temporal resolution. These models utilise unit-level information of the existing thermal fleet (coal, gas, and nuclear) in India, including capacity, efficiency, and year of commissioning. These parameters are leveraged to simulate unit commitment and dispatch operations within the model. For variable renewable energy sources like solar and wind, the model adopts a more granular approach by representing Capacity Utilisation Factors (CUFs) across different timeslices. This approach effectively captures the temporal variability of renewable generation. Similarly, the electricity demand (load curve) is also modelled on a timeslice basis.

8 ORDENA is a mixed-integer linear optimisation program that minimises the Net Present Value (NPV) of investment and operating costs, subject to various technical and operational constraints

9 TIMES (The Integrated MARKAL-EFOM System) model employs linear programming to determine the least-cost energy system over a given time horizon, considering a wide range of technological and resource options

Temporal resolution of the model: Each model year is divided into inter-annual timeslices. Specifically, the model employs a stylised temporal resolution of 288 sub-annual timeslices, capturing seasonal and hourly variations in solar generation, wind generation, and electricity demand. This structure enables realistic simulation of the dispatchable thermal plant operation, hourly renewable generation profiles and the performance of energy storage systems.

The 288 timeslices are formed by considering 24 hours of a representative day for each month of the year, resulting in 24 x 12 = 288 timeslices (see Figure 3.2). Here, the months are referred to as "seasonal timeslices" and the hours of the representative days are termed "day-night timeslices."

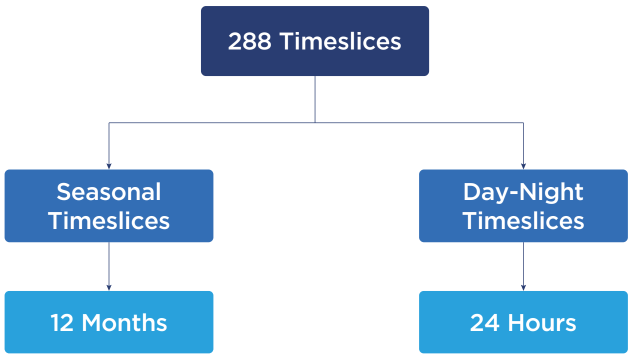


Figure 3.2: Description of timeslices considered in this study

Figure 3.3 shows the schematic structure of the models (TIMES/ORDENA) used. It provides the information on all input-output entities, associated techno-economic parameters and constraints considered in the model.

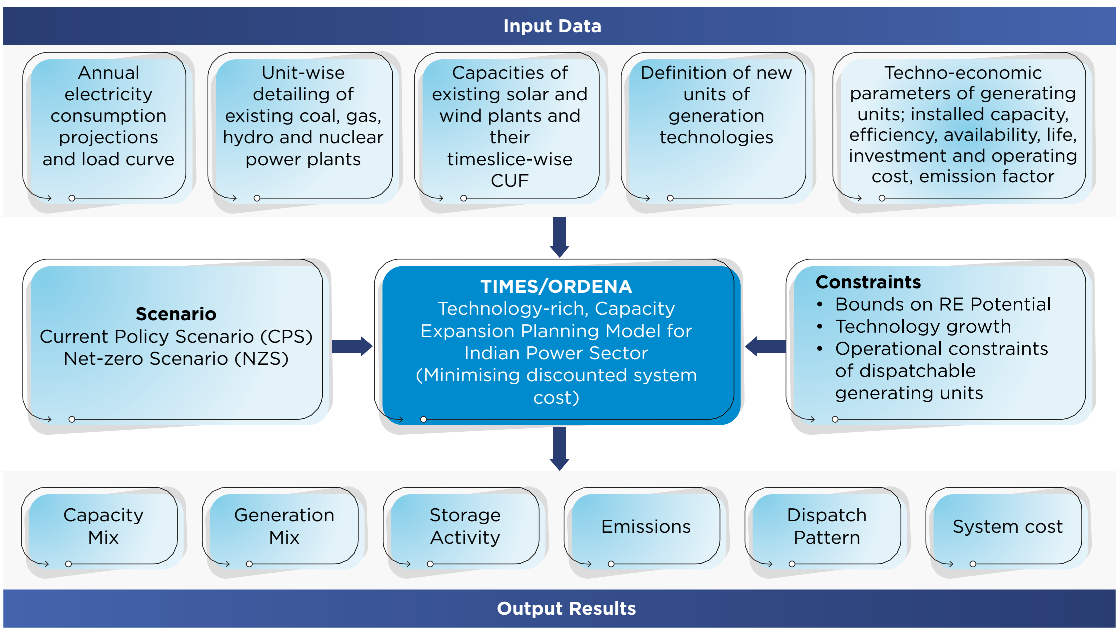


Figure 3.3: Schematic structure of the power sector models

3.4.2 Technoeconomic Assumptions

This study considers all ten major generation technologies currently operating in the Indian power sector: coal, lignite, natural gas, diesel, large hydro, small hydro, nuclear, biomass, solar, and wind. It encompasses both the existing fleet and all prospective capacity additions within these technologies.

Coal and Lignite Power

As of March 2025, India's utility-scale coal-based installed capacity stands at 215.2 GW, of which about 65.3 GW is supercritical, around 4.2 GW is ultra-supercritical, and the remaining roughly 145.7 GW comprises of subcritical units. As per the latest available data for March 2024, captive coal-based installed capacity is estimated at about 46 GW (CEA, 2025). Subcritical plants, being less efficient and more greenhouse gas intensive, are assumed to be retired at the end of their technical life, with no new subcritical capacity additions planned. Future coal capacity expansion is limited to advanced ultra-supercritical (AUSC), ultra-supercritical and supercritical technologies. The operational lifetime for new coal-based generation capacity is assumed to be 40 years. The current installed capacity of lignite-based power plants stands at 6.62 GW; however, no further capacity additions are planned due to their comparatively low efficiency and higher emissions profile.

Nuclear

As of March 2025, India's installed nuclear power capacity is 8.18 GW, comprising 0.32 GW of Boiling Water Reactors (BWR), 5.86 GW of Pressurised Heavy Water Reactors (PHWR), and 2 GW of Pressurised Water Reactors (PWR). For future projections, this study also considers advancements in nuclear technologies and therefore an increase in their efficiency in future. The average plant load factor of the nuclear fleet is assumed to rise from about 78% at present to 80% by 2070. The operational lifetime for a nuclear power plant is assumed to be 60 years.

Solar & Wind

As of March 2025, India has a total installed solar power capacity of 105.6 GW, of which approximately 16 GW is rooftop solar, and the remaining is ground-mounted. In the case of wind energy, the country has an installed onshore wind capacity of around 50 GW. According to the National Institute of Solar Energy (NISE), India's ground-mounted solar photovoltaic (PV) potential is estimated at 3,343 GW. Similarly, the National Institute of Wind Energy (NIWE) estimates the total onshore wind potential at 1,164 GW, based on a hub height of 150 metres Above Ground Level (AGL).

Tables 3.5 and 3.6 present the region-wise potential and the annual maximum capacity expansion constraints considered in this study (for state-wise RE potential, see Annexure B). It is assumed that with incremental improvements in solar PV technology, including the adoption of tracking systems, the capacity utilisation factor (CUF) can reach up to 25% by 2070. For wind energy, it is assumed that all new installations will use turbines with a hub height of 150 metres, enabling CUFs in the range of 25–30%, depending on the region of deployment.

Table 3.5: Technology potential constraints[10,11]

Region	Solar (GW)	Onshore Wind (GW)	Offshore Wind (GW)	Large Hydro (GW)	Small Hydro (GW)	Pumped Hydro (GW)
NR	4,047	286	0	52	8	23
WR	3,573	413	35	8	3	60
SR	2,404	444	35	15	5	53
ER	691	20	0	10	2	18
NER	158	0.5	0	58	3	28
All India	10,872	1,164	70	145	21	181

Table 3.6: Technology expansion constraints (maximum annually)

Year	Solar (GW/Year)	Hydro (GW/Year)	Onshore Wind (GW/Year)	Offshore Wind (GW/Year)	Pumped Hydro (GW/Year)	Battery (GW/Year)
2030-40	50	2	15	1	6	40
2040-50	90	2.5	30	2	6	60
2050-60	120	3	45	3	6	90
2060-70	160	3	55	4	6	125

Hydropower Plants

The existing installed capacity of utility-based large and small hydro power plants in India is 47.73 GW and 5.10 GW, respectively. Over the past five years, the average Plant Load Factor (PLF) for large hydro plants has ranged between 32%-40%, while for small hydro plants, it has varied between 22% to 26%.

Energy Storage

The Battery Energy Storage Systems (BESSs) of 4 hours and 6 hours storage duration with a useful life span of 10-15 years have been considered. The Pumped Storage Plants (PSP) are assumed to have 6-hour storage duration. The PSPs are assumed to have a useful lifespan of 40 years. The round-trip efficiency is taken as 88% for BESS and 80% for PSP.

Technology Cost Assumption

Since most technologies have already reached a mature stage in terms of innovation, no significant reduction in cost estimates has been assumed, except for BESS. Further, investment cost declines are projected based on learning cost curves. Table 3.7 presents the cost estimates for the various technologies considered in the study.

10 ER – Eastern Region; NER- North-Eastern Region; NR – Northern Region; SR – Southern Region; WR – Western Region; PSP – Pumped Storage Plant

11 Note: The solar potential is provided by stakeholder consultations conducted by the Working Group on the Power Sector

Table 3.7: Cost estimates for various generating technologies

in INR Crore/MW (2025 Price)				
Technology	**2030**	**2040**	**2050**	**2070**
Coal (Supercritical)	11.5	11.5	11.5	11.5
Gas	6	6	6	6
Biomass Plant	6	5.9	5.8	5.7
Onshore Wind	7.6	7	6.6	6.4
Offshore Wind	15.4	14.8	14	13.7
Solar PV	4.2	4	3.75	3.5
Hydro RoR	11.3	11.1	11.1	11.5
Hydro RoR (P)	12.3	12.2	12.2	12.5
Hydro Storage	14	13.9	13.9	14.5
Nuclear	14	14	14	14
Pumped Storage Projects (PSP) (on river)	6.4	6.3	6.3	6.7
PSP (closed loop)	6.2	6.1	6.1	6.5
Battery Energy Storage	7.2	6.6	5.6	4.9

Source: *CEA*

The modelling architecture, demand estimation approaches, and techno-economic assumptions outlined in this chapter provide a consistent and transparent basis for analysing India's future power system evolution. Building on this framework, the next chapter presents the results of the power sector modelling, comparing outcomes across scenarios in terms of electricity demand growth, capacity additions, generation mix, system costs, and emissions trajectories.

4

SCENARIO RESULTS

Scenario Results

4

Building on the integrated modelling framework and scenario assumptions outlined earlier, this chapter presents the key results of the power sector analysis. The results highlight how different scenarios influence electricity demand growth, capacity and generation mix, per-capita electricity consumption, investment needs, land and water requirements, and emission intensity of grid electricity. The comparison across scenarios offers insights into the scale, pace, and resource implications of India's power sector transition.

4.1 TOTAL ELECTRICITY CONSUMPTION

Based on the assumptions outlined in the previous chapter, sector-wise electricity consumption is estimated for all end-use sectors, and total electricity demand is derived by aggregating these sectoral demands. Under the Current Policy Scenario, total electricity consumption is projected to reach 6,544 TWh by 2050 and 9,718 TWh by 2070. This represents an increase of more than six times by 2070 compared to 2024 levels, corresponding to a compound annual growth rate (CAGR) of 4.1% over the period 2024–2070.

In the Net Zero Scenario, electricity consumption increases at a faster pace, reaching 8,070 TWh by 2050 and 12,997 TWh by 2070. This represents an increase of more than eight times by 2070 relative to 2024 levels (a CAGR of 4.8% during 2024–2070). Driven by higher electrification across end-use sectors, total electricity consumption in 2070 under the Net Zero Scenario is around 34% higher than in the Current Policy Scenario.

Figure 4.1 presents the sectoral electricity demand projections under the Current Policy Scenario and Net Zero Scenarios. In the Current Policy Scenario, the share of the industrial sector in total electricity consumption remains broadly stable, declining marginally from 41.6% in 2024 to 40.5% by 2070. In contrast, under the Net Zero Scenario, the industrial share increases significantly to 48.3% by 2070. This increase in share is driven by electrification of industrial processes and low-temperature heat, including deployment of heat pumps and community electric boilers, to support industrial sector low-carbon transition.

In absolute terms, electricity demand in the industrial sector is projected to reach around 3,930 TWh by 2070 under the Current Policy Scenario, compared to approximately 6,270 TWh under the Net Zero Scenario. This indicates that industrial electricity consumption in the Net Zero Scenario is more than 1.5 times higher than that in the Current Policy Scenario by 2070.

Electricity demand in the agriculture sector is projected to reach 385 TWh by 2070 under the Current Policy Scenario, compared to 194 TWh under the Net Zero Scenario. The lower electricity demand in the Net Zero Scenario is primarily driven by improvements in pump efficiency and the increasing shift from grid-based electricity for irrigation to solar-powered pumping systems, which are not accounted for in the electricity demand presented here.

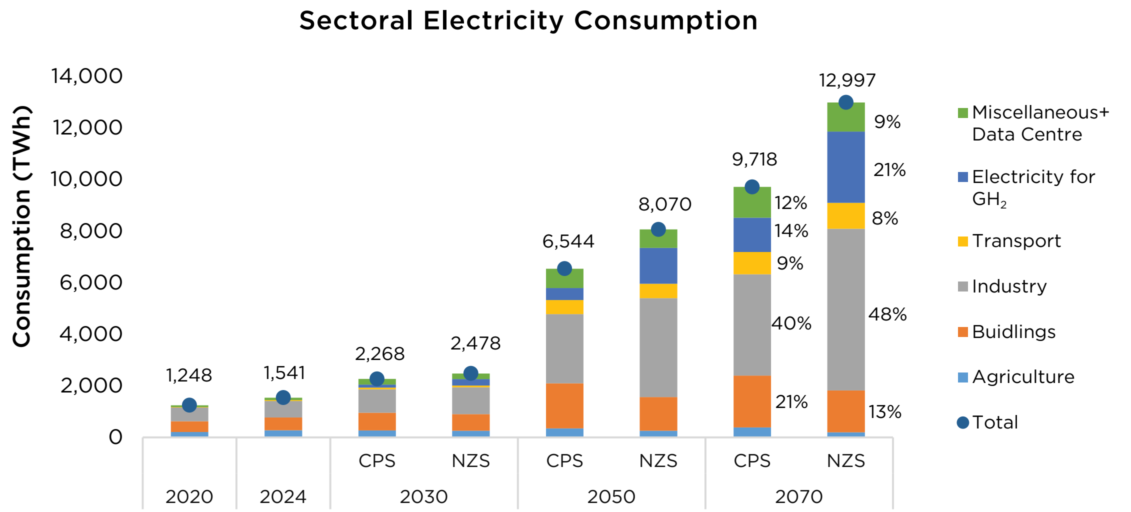


Figure 4.1: Sectoral electricity consumption in Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Electricity demand in the transport sector is projected to reach approximately 550 TWh by 2050 and 870 TWh by 2070 under the Current Policy Scenario. In contrast, under the Net Zero Scenario, electricity consumption rises further to around 1,000 TWh by 2070, despite lower overall transport activity levels. This higher electricity demand is primarily driven by the significantly greater penetration of electric vehicles (EVs). Consequently, the share of the transport sector in total electricity consumption increases from 2.2% in 2024 to nearly 9% under the Current Policy Scenario and about 7.7% under the Net Zero Scenario by 2070.

The buildings sector, which accounts for nearly one-third of total electricity consumption in 2024, is projected to see a declining share by 2070, falling to 20.7% under the Current Policy Scenario and further to 12.5% under the Net Zero Scenario. This reduction in share is primarily driven by the widespread adoption of energy-efficient appliances and improved building performance. In absolute terms, electricity demand in the buildings sector is projected to reach approximately 2,015 TWh under the Current Policy Scenario and about 1,627 TWh under the Net Zero Scenario by 2070.

The miscellaneous sector is projected to witness a substantial increase in its share of electricity consumption, largely driven by the rapid expansion of digital infrastructure and other emerging loads, particularly data centres. Electricity demand from data centres alone is estimated to reach approximately 400 TWh by 2050 and about 700 TWh by 2070.

In addition, electricity demand for green hydrogen production is projected to grow significantly over the long term, reaching around 1,330 TWh under the Current Policy Scenario and approximately 2,770 TWh under the Net Zero Scenario by 2070.

With this, the total electricity required for green hydrogen production is projected to reach approximately 1,350 TWh under Current Policy Scenario and around 2,750 TWh under Net Zero Scenario by 2070.

It is projected that this load will increase four folds by 2050 and five folds by by 2070 compared to current levels.

The electricity required for the data centre is projected to reach approximately 400 TWh by 2050 and 700 TWh by 2070.

Box-1 Cross-Validation of Electricity Demand Projections

The electricity consumption projected in this study is broadly comparable with the projections of India's 20th Electric Power Survey (EPS) report, published by the Central Electricity Authority (CEA). The EPS report provides estimates for both utility-based electricity consumption and self-consumption from Captive Power Plants (CPPs). For 2029-30, this study projects combined utility and captive electricity consumptionof 2,478 TWh under the Net Zero Scenario, which aligns closely with the EPS estimate of 2,516 TWh (1,949 TWh utility and 567 TWh CPP). Similarly, for 2040, this study projects 3,477-3,966 TWh of utility-only electricity consumption, compared with 3,422 TWh projected for 2042 in the EPS report.

4.2 LOAD CURVE AND PEAK DEMAND

The demand profile plays a critical role in the study, as it will substantially impact the capacity mix considering the variability of solar and wind generation, alongside the projected increase in electricity demand from emerging sectors. Figures 4.2a and 4.2b show the load profiles for a representative day for the years 2024 and 2070, respectively. The representative day is constructed by averaging the load for each hour across all days in the month.

The comparison of 2024 and 2070 load profiles shows that India's power system will not only grow several-fold but also shift toward a mid-day, sector-driven demand shape. It is important that capacity addition, storage, and grid investments be planned around these evolving load signatures to keep the transition reliable, affordable, and aligned with climate goals. Recognising and modelling this diversity is essential because it directly informs what kind of capacity India should build (firm, variable or storage) and how much flexibility the grid must accommodate.

While carrying out this study, an in-depth analysis of India's electricity demand profile for 2023-24 and 2024-25 was carried out. This analysis served as the baseline for projecting the future demand profile over the coming decades. Future demand profile projections consider the expected surge in electricity demand from emerging sectors, including:

1) **Data Centres:** With the rapid growth of digital infrastructure and cloud computing, data centres are anticipated to become major consumers of electricity in the coming years. Power demand from data centres is assumed relatively steady across all hours, as these facilities typically operate 24/7.

2) **Electric Vehicles (EVs):** As India aims for large-scale electrification of its transport sector, the charging infrastructure and increased adoption of EVs are expected to add significant new demand to the grid. Power demand from EVs is assumed to have noticeable peaks during late evening and early morning hours when most EVs are likely charged, and a slight increase in demand during afternoon hours.

3) **Green Hydrogen Production:** Recognised as a key future clean energy source, green hydrogen production using renewable electricity will contribute to additional energy demand, especially in

industrial applications like steel, fertilisers, refineries and heavy transport. Power demand from Green Hydrogen is likely to spike during mid-day hours.

By factoring in these new and evolving demand sectors, the study provided realistic and dynamic projections of future electricity profiles, ensuring that India's generation capacity planning, grid stability, and clean energy transition strategies remain aligned with both environmental goals and economic growth.

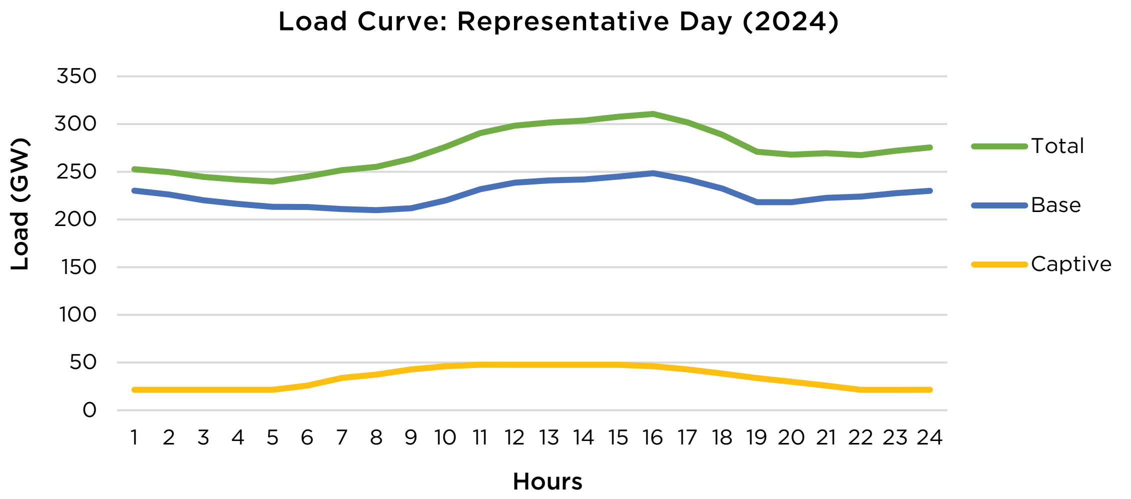


Figure 4.2a: Demand profile for a representative day, 2024

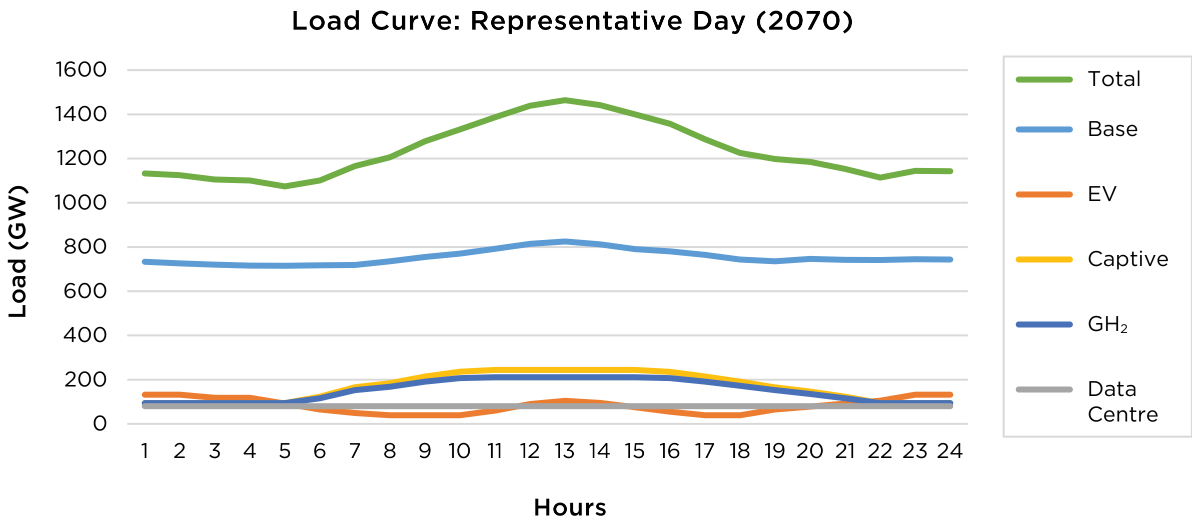


Figure 4.2b: Demand profile for a representative day, 2070

4.3 TRANSMISSION AND DISTRIBUTION (T&D) LOSSES

Transmission and Distribution (T&D) Losses refer to the electricity lost during its transmission and distribution from power plants to consumers. These losses can be technical (primarily due to conductor resistance, equipment inefficiencies) or some non-technical losses (due to theft, meter tampering). Although the T&D losses have improved from a high of 22.84.%

in FY 2013-14 to 17.63% in FY 2023-2024 (CEA, 2025) but it is still higher than the global average of 8%.

The Indian government launched the Revamped Distribution Sector Scheme (RDSS) in July, 2021, to reduce AT&C losses which will lead to a reduction in T&D losses. The scheme focuses on upgrading infrastructure, installing smart meters, strengthening distribution networks, and adopting advanced technologies. The AT&C losses are targeted to be reduced to 12-15% by 2028. Considering the overall initiatives/measures taken by the GoI for AT&C loss reduction in India, this study aims to reduce T&D losses to around 12% by 2030 and gradually decline further to 8% by 2050 and saturate thereafter.

4.4 SCENARIO RESULTS

This section presents the evolution of India's power sector in future under different transition pathways. As India advances toward a more sustainable and increasingly electrified economy, the structure of its power generation mix will undergo rapid change. Rising electricity demand combined with greater daily and seasonal variability and a rising share of variable renewables such as solar and wind, is adding complexity to system operation and planning. In this context, projecting future generation mix requirements becomes not only a technical exercise but a strategic necessity for ensuring long-term reliability, affordability, and climate compatibility.

The key indicators examined are generation mix, capacity mix, GHG emissions, grid emission factors, land and water requirements, investment needs, and per capita electricity consumption. The analysis will also examine implications for grid flexibility, transmission infrastructure, and fossil fuel dependency to provide clear insights to support a sustainable and reliable power system.

4.4.1 Capacity Mix

Meeting India's future electricity needs under different energy transition pathways will require a substantial expansion and transformation of its installed capacity. The capacity mix will not only need to grow to meet rising demand but also shift toward cleaner and more flexible technologies to align with sustainability goals.

In this study, the ORDENA model incorporates both captive and utility-based electricity demand within a single framework by considering two separate nodes. Consequently, the resulting capacity mix reflects the combined requirements for industrial captive power and utility-supplied electricity. In contrast, TIMES power model operates with a single national node to determine utility-based capacity expansion, while the capacity needed to meet industrial captive electricity demand is derived separately from the TIMES energy model. However, for comparability, the results shown here represent the combined capacity for both utility and non-utility (captive) electricity supply.

Figures 4.3a and 4.3b present the outlook for India's installed power capacity by technology, highlighting both absolute capacity and shifts in the technology composition of the overall mix. Models result indicate a significant scale-up in total installed capacity, rising from 535 GW in 2024-25 to 4,650 - 4,750 GW (~9 times) in the Current Policy Scenario (CPS) and 6,800 - 7,350 GW (~14 times) in Net Zero Scenario (NZS) by 2070. A pronounced transition toward variable RE, primarily solar PV and wind, is evident across both the scenarios seen from ORDENA and TIMES models driven by falling technology costs and competitive Battery Energy Storage Systems (BESS) post-2040, which enable large-scale integration of intermittent renewables into the grid. In terms of the contribution of solar and wind, their share in capacity increases from 26% in 2023-24 to 88% and 91% in Current Policy Scenario and Net Zero scenarios, respectively. However, in terms of total RE (including Hydro and Biomass), the share is expected to rise sharply from 38% in 2023-24 to 91-93% by 2070. Delving resource-wise:

- Massive rise in solar PV capacities from 110 GW in 2024-25 to 4,900-5,650 GW by 2070 in Net Zero Scenario (NZS) compared to 3,150-3,250 GW in Current Policy Scenario (CPS). This more than 50 times increase in solar capacity also has huge land implications, which are discussed separately in the social aspects of transition report.
- Wind energy also expands strongly from 54 GW in 2024-25 to 1,050-1,300 GW in Net Zero Scenario vs 900-1,050 GW in Current Policy Scenario, within which offshore wind potential is largely from the coasts of Gujarat and Tamil Nadu by 2070.
- Biomass grows modestly from 11.6 GW in 2024-25 to 30–34 GW by 2070. Hydropower (including small hydro) also see a modest increase, constrained by potential, from 53 GW to 140-155 GW by 2070.

This rising share of Variable Renewable Energy (VRE) requires a corresponding expansion of energy storage to maintain system reliability and flexibility. Battery Energy Storage Systems (BESS) are projected to grow from less than 50 GW in 2030 to around 1,300–1,400 GW in the Current Policy Scenario (CPS) and 2,500–3,000 GW in the Net Zero Scenario (NZS) by 2070. Pumped Storage Plants (PSPs) are also expected to play a crucial role in providing long-duration storage and grid stability, increasing from 13–19 GW in 2030 to about 110 GW in CPS and 150–165 GW in NZS by 2070.

Power sector capacity choices are primarily shaped by relative fuel costs, domestic resource availability, and reliability requirements. Unlike the EU and the United States, where natural gas is relatively abundant and affordable, India faces structural constraints due to limited domestic gas supply and the high cost of imported LNG. Consequently, natural gas plays only a limited role in both scenarios over the long term. The modelling results do not indicate new investment in gas-based generation, as available domestic gas is prioritised for non-power uses. Existing gas plants will be gradually retired by 2050, leaving no gas-based capacity in the generation mix thereafter.

India is making good progress in adding renewable generation capacity, with energy storage of up to 4 hours. However, large-scale up of renewables depends on long-duration energy storage technologies. These remain expensive and not yet available at scale. India has ambitious nuclear power targets. However, nuclear has high capital costs and long gestation periods. Consequently, coal-based generation is expected to play a key role in the near to medium term to meet rising electricity demand, provide baseload supply, and ensure grid reliability during the transition. In the Current Policy Scenario, coal capacity rises from 268 GW (utility and non-utility) in 2025 to a peak of 450–470 GW by 2050. In the Net Zero Scenario, coal peaks earlier at 420–435 GW by 2045 before declining as long-duration storage and clean alternatives become more cost-competitive. These estimates could change if long-duration energy storage technologies become commercially viable and if nuclear energy, in particular small and modular reactors become cheaper, enabling faster capacity addition.

Nuclear power assumes a critical role alongside accelerated renewable deployment. In the Current Policy Scenario, nuclear capacity increases from 8.18 GW in 2024–25 to 87–135 GW by 2070. The Net Zero Scenario reflects the achievement of India's nuclear mission target of 100 GW by 2047, as announced in the Union Budget 2025–26, with total nuclear capacity projected to reach around 295–320 GW by 2070.

The net-zero pathway envisages a substantially higher share of renewables and nuclear over the long term, contingent on major reductions in technology costs, rapid deployment of long-duration storage, timely addition of nuclear capacity, and significant grid flexibility enhancements. If these conditions do not materialise within expected timelines, coal is likely to remain a key fuel for meeting growing electricity demand.

Over time, as technologies enabling large-scale renewable integration mature, coal capacity additions decline and a portion of the existing fleet is retired based on plant lifetimes. By 2070, remaining coal capacity in the Net Zero Scenario is projected at 145–160 GW, significantly lower than 225–270 GW in the Current Policy Scenario. A substantial share of this residual capacity in the Net Zero Scenario is expected to operate at low utilisation and may remain as reserve capacity.

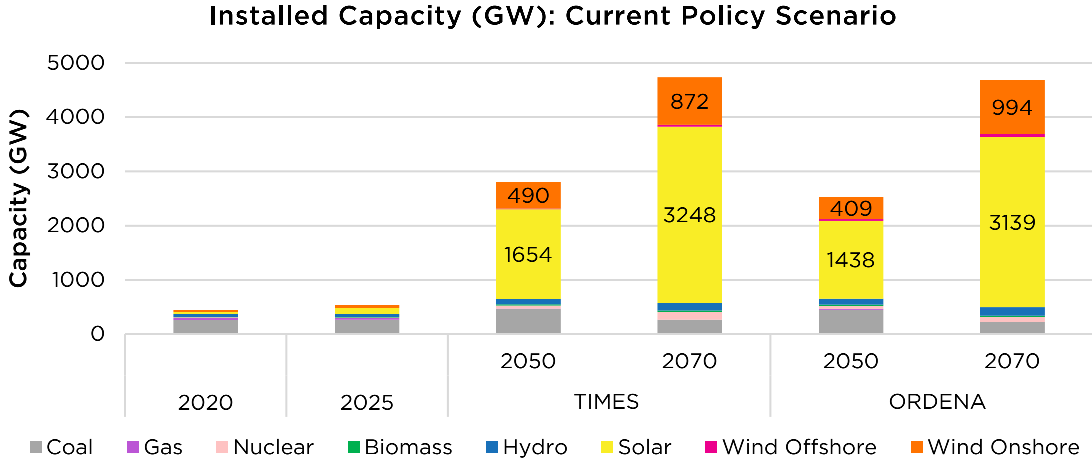


Figure 4.3a: Projected capacity mix in Current Policy Scenario (2050 and 2070) using two models

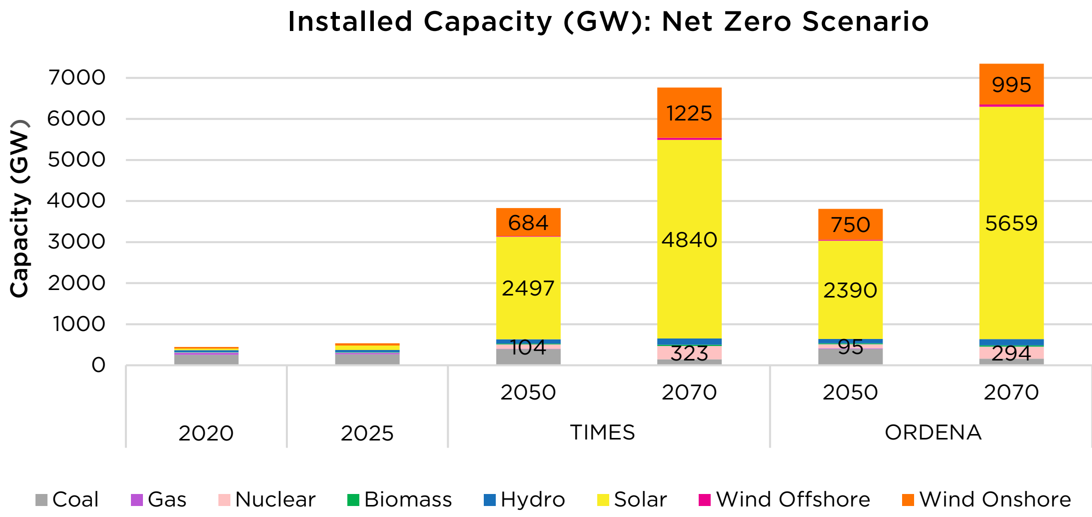


Figure 4.3b: Projected capacity mix in Net Zero Scenario (2050 and 2070) using two models

The capacity share of each technology under Current Policy Scenario and Net Zero Scenario across two power sector models is presented in Table 4.1.

Table 4.1: Capacity mix across two models in Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Generation Technologies	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%

Box-2 Alternate Scenarios to achieve Power Sector Net Zero

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 Net Zero (NZ) 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. In case of nuclear, there could be delays because of higher capital costs, challenges in land-acquisition, public perception issues and long gestation periods. In case of Renewables, there could be delays because of land constraints, grid integration challenges. 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.

This shift reflects a broader structural transformation in India's capacity planning toward a more flexible, storage-integrated, and low-carbon power system capable of meeting the country's growing electricity demand while aligning with long-term sustainability goals.

4.4.2 Generation Mix

Figures 4.4a and 4.4b show the trend and share of electricity generation from different sources until 2070. First, the total electricity generation grows from ~2,000 TWh in 2025 to 7,350-7,700 TWh in 2050 and 11,100-11,200 TWh in 2070 under Current Policy Scenario (CPS), and 9,700-10,200 TWh in 2050 and ~16,000 TWh in 2070 under Net Zero Scenario (NZS). Second, RE share in generation increases from 20% in 2024-25 to over 80% in Current Policy Scenario and over 85% in Net Zero Scenario by 2070, reflecting the dominance of renewables in future electricity generation. Third, the contribution of nuclear increases many-fold, with the contribution increasing from 3% to 13-14% in Net Zero Scenario vs 5-8% in Current Policy Scenario, reflecting its growing role in displacing coal-based generation and providing carbon-free baseload power. Lastly, coal's share in overall electricity generation remains 6-10% by 2070 in Current Policy Scenario, while in Net Zero Scenario, there is almost no generation from coal capacity. While both scenarios see a significant decline in coal capacities, PLF during the intermediate period, however, hovers around 62-65% indicating high utilisation. Any ramifications of decreasing this will also have implications for grid stability. A significant coal capacity in Net Zero Scenario (145-160 GW) may be reserve capacity rather than actively generating.

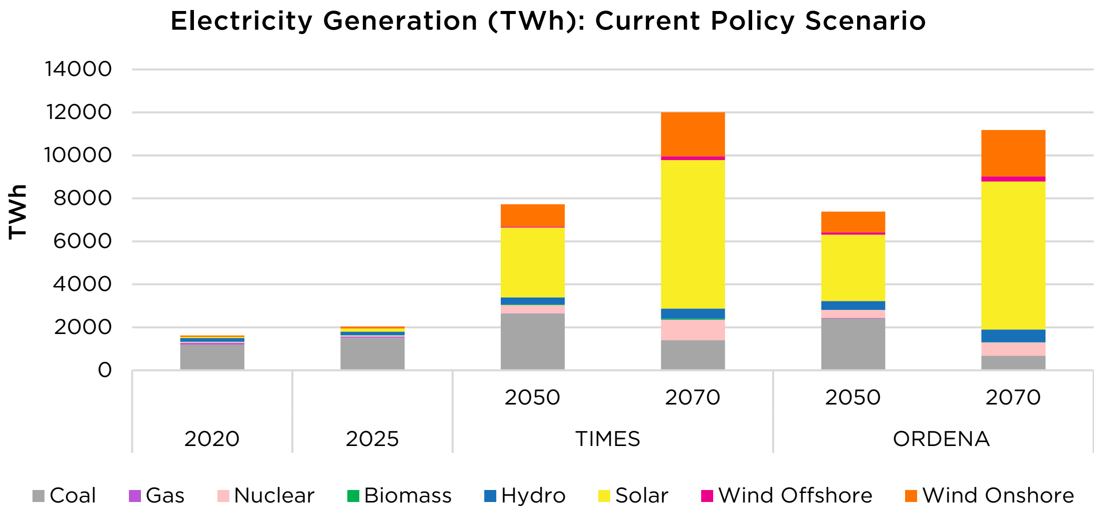


Figure 4.4a: Projected generation mix in Current Policy Scenario (2050 and 2070) using two models

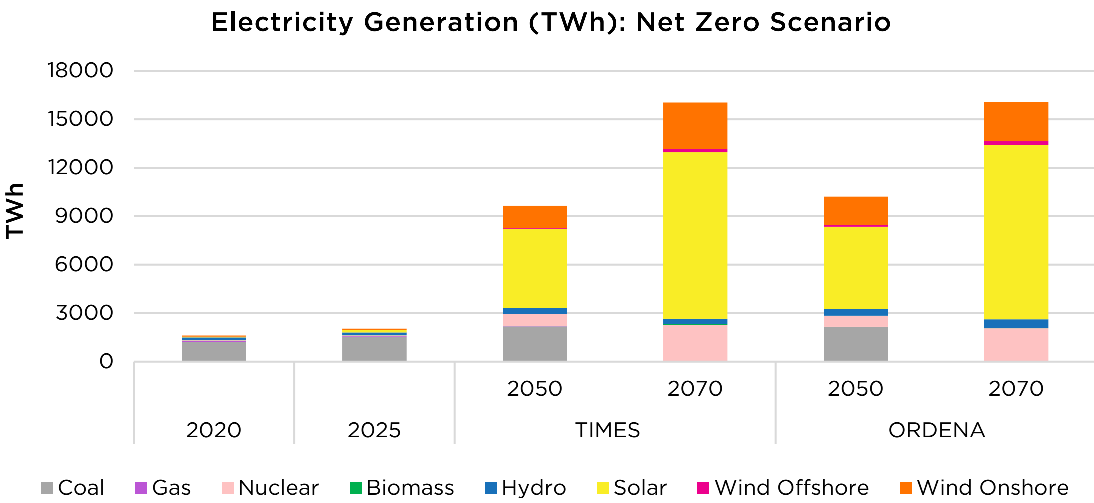


Figure 4.4b: Projected generation mix in Net Zero Scenario (2050 and 2070) using two models

Table 4.2: Generation mix across two models in Current Policy Scenario and Net Zero Scenario

Generation Technologies	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%

4.4.3 Per Capita Electricity

In FY 2023-24, India's per capita electricity consumption stood at approximately 1,400 kWh, representing a nearly 46% rise from about 957 kWh in FY 2013-14. This growth reflects improved access, rising industrial and residential demand, and wider grid reliability across urban and rural households.

India's per capita electricity consumption is projected to increase steadily as economic growth, urbanisation, and electrification of households and industries continue, as shown in Figure 4.5. Under Current Policy Scenario, the per-capita electricity consumption increases by ~3.4 times by 2050 and ~5 times by 2070 (over 2024 levels). This trajectory assumes continued reliance on a mixed energy basket with moderate energy efficiency improvements and rising demand from sectors like manufacturing, transport (especially electric vehicles), and residential cooling and green Hydrogen.

In Net Zero Scenario, electricity consumption per capita would rise even more sharply. This is driven by large-scale electrification of sectors like transport, cooking, and industry, replacing fossil fuels with low-carbon electricity. The per capita electricity use reaches ~4.5 times by 2050 and ~7 times by 2070, with faster growth especially post-2030 as low-carbon energy infrastructure scales up. However, this path also assumes significant gains in energy efficiency, which again reduces the electricity consumption.

By 2050, India's per-capita electricity consumption is expected to reach 4,800 kWh in Current Policy Scenario and 6,400 kWh in Net Zero Scenario. By 2070, the per capita electricity consumption is projected to reach 7,400 kWh in Current policy scenario and 10,000 kWh in Net zero scenario. This puts us in the league of average per-capita electricity consumption seen in other economies such as Germany (~6316 kWh in 2022) and France (~6,649 kWh in 2022) (World Bank). However, it remains below the standards seen in other developed economies such as the United States (~12,968 kWh in 2022) and South Korea (~11,706 kWh in 2022).

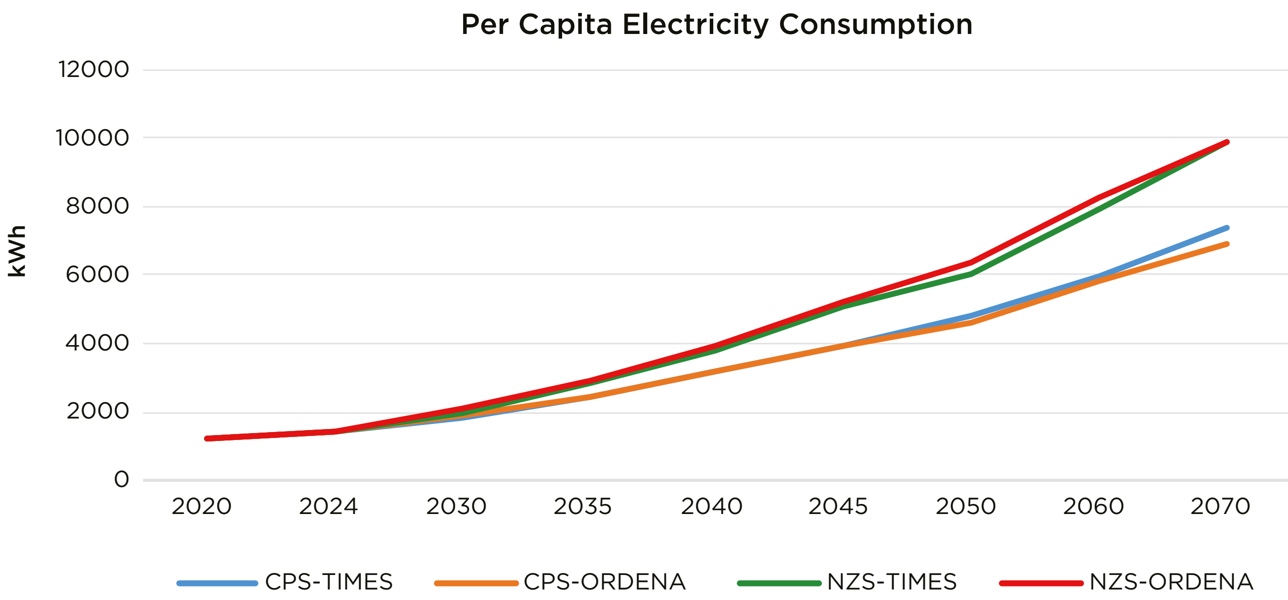


Figure 4.5: Projections of per capita electricity consumption under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

4.4.4 Land and Water Requirement

As India aims to meet its growing electricity demand while transitioning to a low-carbon economy, understanding the future land and water footprint of various energy technologies is critical. Each power generation source, like solar, wind, thermal, and nuclear, has distinct resource requirements that will shape infrastructure planning, environmental impact, and policy decisions.

Land Requirement

Thermal power, which remains a major component of India's energy mix, has a substantial land footprint. Coal-based plants require land for the main plant area, coal handling and storage, ash disposal facilities, and often dedicated water reservoirs. Nuclear power plants occupy a relatively compact land footprint compared to solar or wind, but require stringent site selection to meet safety, seismic, and water availability criteria. In addition to the plant infrastructure, a safety (exclusion) zone of approximately 1-1.5 km radius is mandated around each facility where no public habitation is allowed. Beyond this, a sterilised zone (up to 5 km) and emergency planning zone (10–16 km) are also defined around large nuclear reactors for contingency planning. These safety buffers significantly increase the effective land area influenced by a nuclear installation, even if not directly used.

Utility-scale solar PV installations typically require about 3 acres (~1.22 hectare) of land per MW of capacity. Wind energy generally has a lower direct land-use intensity, since turbines occupy relatively small footprints within large tracts of land that can often continue to be used for agriculture or grazing. However, turbine spacing requirements imply that large geographical areas are needed to accommodate high levels of future capacity. The specific land-use assumptions adopted in this study for the land requirement estimation for different generating sources are provided in Annexure C.

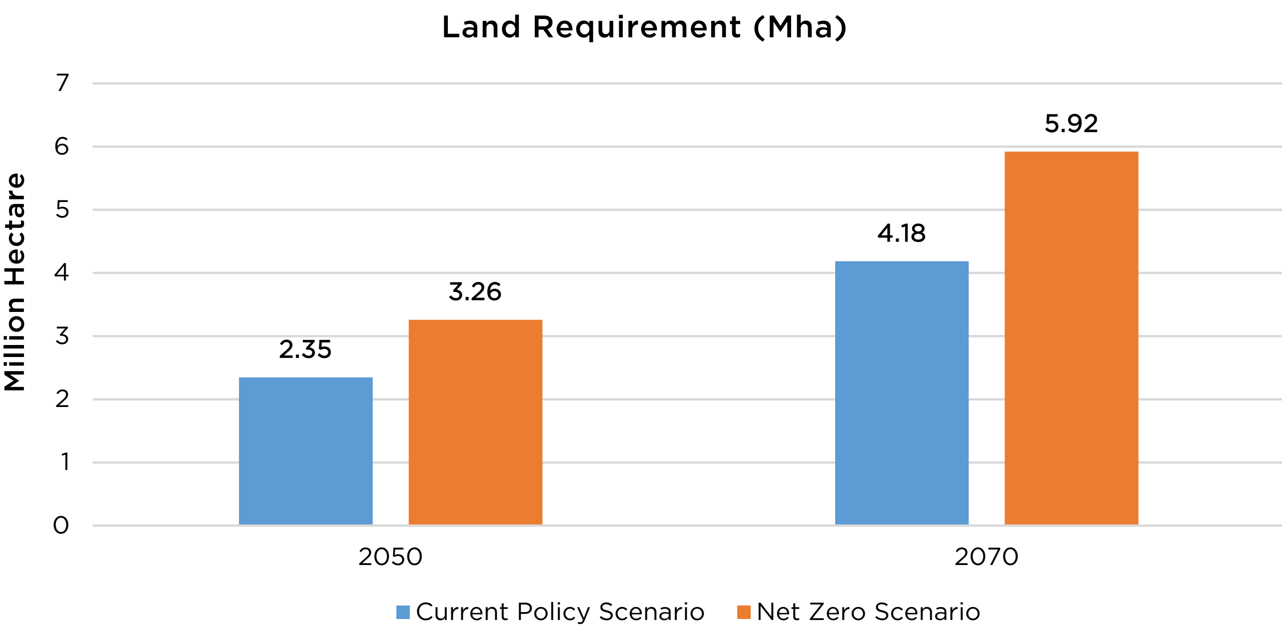


Figure 4.6: Projected Land requirement for electricity generation under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

Based on the assumed land requirements for installing 1 MW of capacity across different generation technologies, and the planned capacity mix derived from modelling results, the estimated land requirements under various scenarios are illustrated in Figure 4.6. Land requirements show a steady rise across all scenarios as renewable energy expands. In Current Policy Scenario, land use grows from 0.68 Mha in 2030 to 2.35 Mha in 2050, reaching 4.18 Mha by 2070 (7.5% of the total wasteland area of 55.76 Mha identified in Wastelands Atlas of India 2019). In contrast, the Net Zero Scenario sees a much higher land demand, increasing from 0.82 Mha in 2030 to 3.26 Mha in 2050, reaching 5.92 Mha by 2070 (11% of the total wasteland under Net Zero Scenario).

Water Requirement

Thermal power plants are highly water-intensive, with consumption typically ranging from 3 to 7 m^3/MWh, primarily for cooling systems and boiler feed. A significant portion of this water is recycled internally. For instance, older plants using cooling towers see their consumptive water use drop from approximately 7 m^3/MWh without wash water recirculation to around 5 m^3/MWh when recirculation is implemented. Most of the water (typically 1 or more m^3/MWh) for boiling operations is fresh makeup water, needed to compensate for losses like evaporation, blowdown, and steam leaks. In nuclear power generation, water consumption remains high due to the need for continuous cooling, particularly in Pressurised Heavy Water Reactors (PHWRs) and Light Water Reactors (LWRs).

In contrast, solar plants have minimal water needs, limited to occasional panel cleaning, though in arid zones, this may become a stress factor requiring innovative dry-cleaning or water-efficient technologies. Water usage in the case of wind power is negligible, making it one of the least water-intensive energy sources.

The production of green hydrogen through electrolysis requires approximately 9 litres of purified water per kilogram of hydrogen for the electrochemical reaction. Including additional needs for cooling and pre-treatment, total water consumption rises to about 18–25 litres per kilogram. However, cooling water can typically be recycled in closed-loop systems, which helps reduce net water usage and enhances the sustainability of green hydrogen production.

The assumptions for the water-factor adopted in this study for the water requirement estimation for electricity and hydrogen generation are provided in Annexure D.

The water requirements of the power sector will vary across different scenarios as India transitions towards a cleaner capacity mix, as shown in Figure 4.7. In the Current Policy Scenario, water consumption is projected to rise from 6.46 billion cubic meter/yr per year in 2030 to 10.90 bcm/yr in 2050, before slightly decreasing to 9.13 bcm/yr by 2070 due to improvements in efficiency and a gradual shift away from thermal (coal-based plants) generation to RE generation. In the Net Zero Scenario, water demand is slightly higher than Current Policy Scenario in 2030 (6.63 bcm/yr) but increases significantly by 2050 (11.07 bcm/yr) and further drops to 9.90 bcm/yr by 2070, due to the large-scale adoption of renewables, which require minimal water. However, it is higher than Current Policy Scenario due to higher nuclear installation and green hydrogen production in Net Zero Scenario by 2070. The increase is concerning, especially in the context where per-capita water per capita annual availability has fallen sharply from 5,177 m^3 in 1951 to 1,486 m^3 in 2021, already breaching the “water-stressed” threshold of 1,700 m^3 defined by the United Nations.

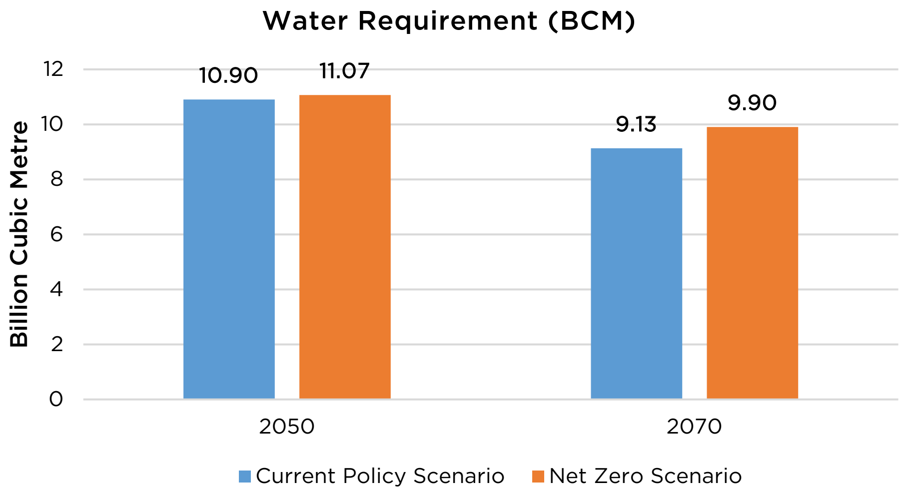


Figure 4.7: Water requirement under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

4.4.5 Investment Requirement

To meet future electricity requirements, substantial investments are required to expand generation capacity alongside transmission and distribution infrastructure. Moreover, the capacity expansion driven by increasing penetration of variable renewable energy (VRE) sources such as solar and wind must be supported by investments in flexibility resources, including Battery Energy Storage Systems (BESS) and Pumped Hydro Storage (PHS). These technologies will play a critical role in managing the intermittency of VRE, ensuring grid stability, and meeting peak load requirements. Without adequate storage integration, the reliability and efficiency of renewable generation expansion could be significantly compromised.

In parallel, investments must prioritise the development of transmission and distribution (T&D) networks to connect high-potential renewable energy zones, often located in remote areas with limited or no grid access. Constructing new transmission corridors and substations, along with integrating smart grid technologies, is essential for evacuating power from these regions and ensuring system reliability. In many regions, the current grid is also outdated and ill-equipped to manage the variability of renewable energy sources or the increasing number of decentralised generation points. A well-coordinated investment strategy across generation, storage, and T&D infrastructure will form the backbone of a reliable, efficient, and future-ready power sector.

This study considers the capital cost requirements for power sector expansion across three key areas:

(1) Capital expenditure (Capex) for various electricity generation technologies

(2) Capex for stationary energy storage systems

(3) Capex for Transmission and Distribution (T&D) infrastructure

The investment required for capacity expansion is estimated based on the unit capital cost per MW of plant installation for different generation technologies. Assumptions for unit capital cost considered for various generating sources in this study are provided in Table 3.7. However, for transmission expansion, a rule-of-thumb approach based on a standard cost per MW of added generation capacity is considered.

For estimating transmission expansion costs, this study applies a simplified rule of thumb based on proportional cost allocation. Under typical conditions in a conventional power system, transmission expansion costs are assumed to be half of the total generation cost, while distribution expansion costs are taken as one-fourth of the generation cost. This results in a cost ratio of Generation: Transmission: Distribution to be 4:2:1. The same assumption is applied for infrastructure planning for future coal, nuclear, and hydropower generation.

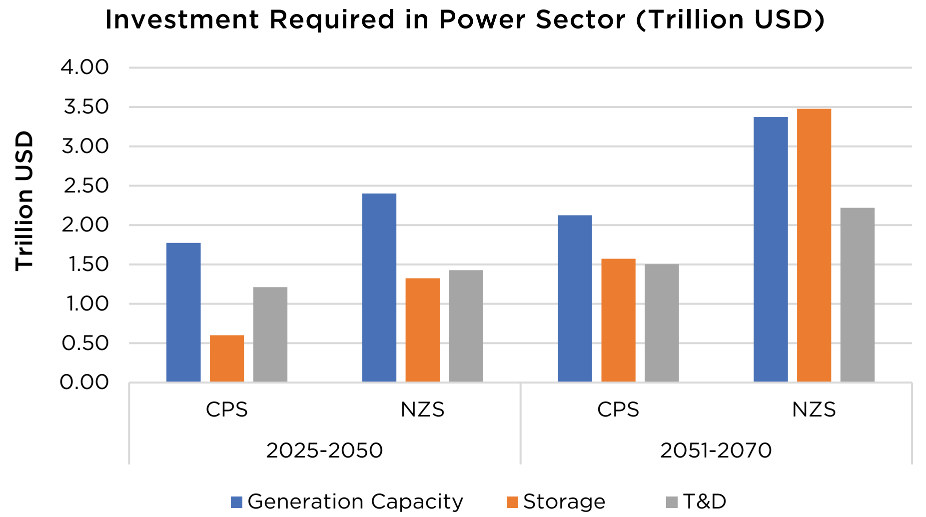


Figure 4.8: Projected investment requirements under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

In contrast, power systems with VREs require significantly higher transmission costs. This is mainly due to the need for additional infrastructure such as Flexible AC Transmission Systems (FACTS), DC-to-AC conversion equipment, harmonic filters, and advanced systems for smart grid operation and management. To capture this added complexity and cost, the ratio is adjusted to 4:3:1 for infrastructure expansion in solar and wind power generation. This approach offers a practical estimation method for planning purposes, particularly when detailed project-specific transmission routing and costing data are unavailable.

Figure 4.8 and Table 4.3 present the estimated cumulative investment requirements in India's power sector, across generation, storage, and transmission & distribution, under the Current Policy Scenario (CPS) and Net Zero Scenario (NZS) over the periods, highlighting significantly higher investment needs under the net-zero pathway.

The investment requirement in Current Policy Scenario will primarily focus on meeting incremental demand growth with a mix of conventional and renewable sources alongside essential expansion of transmission and distribution infrastructure. The total investment needed in Current Policy Scenario is USD 8.79 trillion. Out of that 69% is for capacity expansion (including both generation capacity and storage capacity), and 31% is for transmission and distribution infrastructure expansion[12].

In contrast, Net Zero Scenario demands a far more ambitious investment strategy aimed at the complete transformation of the power sector by 2070. This requires accelerated deployment of renewable energy, widespread adoption of flexibility resources like battery storage and

12 Exchange rate is assumed to be 1 USD = 80 INR.

pumped hydro, and extensive electrification across end-use sectors. Transmission and distribution infrastructure must be significantly scaled up and modernised to accommodate variable generation and distributed energy resources. The total investment needed in Net Zero Scenario is USD 14.23 trillion, out of which 74% is for capacity expansion, (including both generation capacity and storage capacity), and 26% is for transmission expansion. The capacity expansion includes both generation capacity and storage capacity. Achieving net zero will necessitate a coordinated, high-investment approach across generation, storage, grid infrastructure, and digital systems.

Table 4.3: Investment requirements under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

	2025-2050		2025-2070	
	CPS	NZS	CPS	NZS
Generation Capacity (Trillion USD)	1.77	2.40	3.90	5.78
Storage (Trillion USD)	0.60	1.32	2.17	4.80
T&D (Trillion USD)	1.21	1.43	2.72	3.65
Total (Trillion USD)	3.58	5.15	8.79	14.23

Recognising that the feasibility of power sector low-carbon transition hinges as much on financial architecture as on technological readiness, NITI Aayog constituted a Working Group (WG) which examines how the power sector transition can be financed and the structural constraints that shape capital mobilisation. WG addresses the critical issues, including the availability and cost of capital, risk allocation across public and private actors, the role of concessional and blended finance, domestic financial sector preparedness, and the alignment of regulatory and institutional frameworks. For detailed information about this, the WG report on Financing Needs (Vol. 9) can be referred.[13]

4.4.6 Grid Emission Factor

The grid emission factor represents the average amount of carbon dioxide (CO_2) emitted per unit of electricity generated and supplied to the power grid, usually expressed in kg CO_2 per kWh. It reflects the carbon intensity of the electricity mix, depending on the share of fossil fuels and renewables in the grid. It serves as a key indicator of the carbon intensity of a country's power mix and plays a vital role in India's efforts toward low-carbon transition.

The grid emission factor is also crucial in assessing the effectiveness of electrification in transport and industry sectors, such as penetration of electric vehicles, industrial electrification and green hydrogen production in reducing overall emissions. A high emission factor limits the climate benefits of these technologies, whereas a declining grid emission factor, driven by increased renewable integration, enhances the climate advantage of electrification across sectors, supporting India's transition to a low-carbon economy.

As per the report from CEA, India's grid emission factor (the average CO_2 emitted per unit

13 The estimate presented in this study includes the investment requirements from both captive and non-captive expansion under power. However, the report on Financing Needs (Vol. 9) treats the investment need for captive under industrial sector needs,

of electricity supplied to the grid) in 2025 is approximately 0.71 $kgCO_2/kWh$[14]. Under Current Policy Scenario, where renewable scaling is at a moderate pace, and almost 240 GW of new coal addition is envisaged by 2045, India's grid emission factor declines but at a slow pace from 0.71 in 2025 to 0.328 by 2050 and 0.067 kg CO_2/kWh by 2070 (see Figure 4.9).

In contrast, under Net Zero Scenario, which features massive solar and wind deployment coupled with grid-scale storage, phased coal retirements, and strategic retrofitting, the grid emission factor declines sharply to ~0.25 to 0.27 kg CO_2/kWh by 2050, representing a ~65% reduction from current levels of ~0.71 kg CO_2/kWh. This steep decline is contingent on meeting India's non-fossil capacity targets and deploying flexible systems to handle seasonal variability in renewable generation.

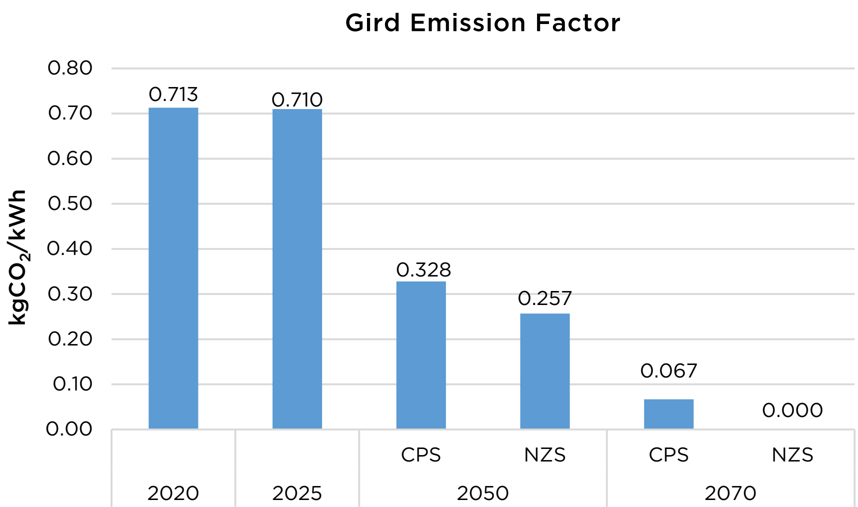


Figure 4.9: Grid emission factors under Current Policy Scenario (CPS) and Net Zero Scenario (NZS)

4.5 LIMITATIONS

The results presented in this report are derived from a scenario-based power sector 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.

1. **Deterministic Modelling Approach:** The current analysis is deterministic and relies on a transparently defined set of assumptions on demand growth, load curves, technology costs, fuel prices, technology performance trends, and the evolution of clean energy systems. 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 one plausible scenario or estimate of the future, rather than a prediction. The findings are indicative and contingent on specific modelling choices, rather than definitive or exhaustive. However, given the multiple exercises taken, including by NITI Aayog and CEA separately, with reasonable

14 The table for weighted average emission factor of the Grid as published by CEA in CO_2 baseline database report from 2013-14 onwards is given in Annexure E.

overlap, there is high confidence in the directionality and insights indicated. Readers should not focus on specific numbers but rather the trends, e.g., that the power sector will continue to grow fossil fuels for some years before peaking emissions.

2. **Demand Modelling and Economy-Energy Linkages:** In this study, the electricity demand used in power sector model is estimated through a soft-coupled framework (energy sector model) with the rest of the economy. While this allows for transparent scenario design and tractable computation, it does not constitute an equilibrium analysis guiding an "optimal" shift of energy from other fuels to electricity; such shifts are treated as exogenous inputs informed by broader pathways.

3. **Demand Response and Distributed Energy Resources:** A potentially significant source of divergence arises from the growth of behind-the-meter and distributed energy technologies, such as on-site storage, electric vehicles acting as flexible loads or suppliers, and digitally enabled demand response. While the model considers India's existing and future captive power capacity expansion along with rooftop solar, the future scale and system interaction of these new technologies remain highly uncertain. Their evolution will depend critically on policy and regulatory design, including tariff structures and net-metering rules. This will influence electricity consumption and load profile.

4. **Scenario Coverage and Sensitivity Analysis:** The study presents a single reference trajectory for each scenario, and hence does not explicitly conduct sensitivity analysis across key uncertain parameters such as solar and wind generation profiles, load curves, cost trends, and plant outages. While uncertainty around these parameters can be substantial, the pathway presented is intended to represent a plausible mid-range trajectory, and not envisaged as risky or extreme.

5. **Temporal Resolution and Extreme Events:** For computational and tractability reasons, the model relies on representative demand profiles and uses hourly matching to determine a least-cost capacity mix. This approach does not explicitly capture tail-risk conditions or extreme system stress events, such as coincident periods of low renewable output, extreme heat-driven demand, drought-related hydro constraints, or fuel supply disruptions. Climate change may further increase both short-term volatility and long-term shifts in demand and resource availability. Though the model considers planning reserve margins, addressing these risks could require additional reserve margins, storage, or firm capacity, potentially increasing system costs.

6. **Spatial Granularity:** The study is conducted at a limited spatial resolution, using aggregated national representations rather than a fully regional/state-level disaggregation. As a result, localised constraints related to RE potential, resource availability, and sub-regional demand growth may not be fully reflected.

7. **Transmission Representation:** In this study, transmission expansion is not endogenously optimised within the model. Though transmission cost is exogenously calculated for the projected capacity expansion, the timing and feasibility of network expansion, especially for integrating high shares of variable RE, could materially affect system outcomes.

8. **Load Shape Evolution:** Future electricity load curves are based on projected demand

growth and known electrification trends, but structural changes in load shapes, arising from widespread EV adoption, air-conditioning penetration, industrial electrification, and digital demand response, are only partially captured.

9. **Cross-Border Interactions:** In this study, cross-border electricity trade is not explicitly modelled. While current levels of interconnection are modest, deeper regional power integration could alter capacity requirements, flexibility needs, and system costs over time.

10. **Scaling Constraints and Implementation Risks:** The last uncertainty not explicitly varied across scenarios relates to barriers to scaling. This includes issues of (1) land availability, which is quantified as being feasible in the study in terms of total square kilometres required, but it may lead to logistical delays and cost increases, (2) availability and terms of finance for capital-intensive technologies, (3) global supply chains, and (4) skilled human capacity.

4.6 FUTURE ENHANCEMENTS

Future iterations of this work will seek to address identified limitations by expanding sensitivity analysis, incorporating multi-year weather datasets and full 8,760-hour modelling for production cost modelling, representing a broader portfolio of storage and flexibility options, refining cost and performance assumptions, improving the treatment of captive and behind-the-meter behaviour, and bringing scaling constraints directly into the modelling framework. These enhancements will benefit from richer datasets and increased computational capacity, which remains a binding constraint given the vast number of possible future pathways.

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 power-sector planning as India advances toward its Net Zero objectives.

5

CHALLENGES AND OPPORTUNITIES

Challenges and Opportunities

5

India has the dual challenge of sustaining high economic growth while limiting or reducing emissions. Realising the development objective will entail a major transformation in power infrastructure, the ability to leverage India's demographic dividend, robust, low-carbon manufacturing competitiveness, and the affordability of power. This chapter first examines power-sector challenges across the value chain: technical, financial and regulatory, and then discusses opportunities that must be leveraged to build Viksit Bharat by 2047.

5.1 CHALLENGES

The broad themes under which the challenges discussed in the next section are organised are as follows:

(i) Generation Sector

(ii) Transmission and Distribution Sector

(iii) Cross-cutting Innovation and Sustainability

(iv) Project Financing

(v) Policy and Regulatory

5.1.1 Generation Sector Challenges

a. **Rising Need for Grid Stability and Reserves:** Solar and wind power have expanded rapidly in India, but their inherent intermittency poses growing challenges for grid stability. The Indian power system operates within a narrow frequency band, and even small imbalances between supply and demand can lead to disruptions. Sudden variations, such as a surge in wind generation or cloud cover reducing solar output, require near-instantaneous adjustments by grid operators. Currently, grid stability is largely maintained through coal- and hydro-based generation.

As the share of coal in the generation mix declines over time, maintaining system stability with higher renewable penetration and reduced conventional capacity presents a significant challenge. Energy storage, therefore, emerges as a critical requirement for managing the variability associated with RE integration. Beyond a limited number of pumped hydro storage projects, India does not yet have a robust, large-scale storage network. Battery technologies, including lithium-ion and other battery energy storage systems (BESS), are starting to roll out, but their deployment remains far below what is required to support a renewables-dominated grid. Until storage solutions are deployed at scale, managing variability and ensuring system reliability will remain among the most significant obstacles in India's energy transition.

b. **Coal Dependence:** Despite significant progress in RE, coal continues to contribute nearly 73% of India's utility electricity generation in 2024-25. Coal-based plants offer technical benefits such as grid stability, reliability, while providing baseload power. While India is rapidly scaling up RE capacity, the intermittency of solar and wind power continues to pose challenges for round-the-clock electricity supply. As a result, coal-fired generation remains essential in the near to medium-term to ensure grid stability and meet rapidly growing electricity demand.

   The low-carbon transition in the power sector raises three key issues. First, higher capital costs associated with new coal capacity: new coal installations, based on advanced ultra-supercritical (AUSC) or ultra-supercritical (USC) technologies, involve significantly higher upfront capital costs compared to older subcritical plants. Second, the cost and performance implications of flexible coal operations: as RE penetration increases, coal plants will be increasingly required to operate at partial loads to balance supply and demand. This can lead to reduced efficiency. Third, the risk of stranded assets: over the long term, a significant share of newly built or upgraded coal plants may face early retirement before completing their planned operational life.

c. **New Technology Limits:** Integrating higher shares of solar and wind power is not only a question of adding generation capacity but also of the power system's ability to absorb variable renewable energy safely and reliably. Various studies show that with existing T&D infrastructure, India can handle increasing shares of renewables up to a point (IEEFA, 2023). But beyond that, there is a need to upgrade the existing system, such as building stronger transmission networks, deploying advanced grid management tools, and enhancing flexibility through modern technologies.

5.1.2 Transmission and Distribution Sector Challenges

a. **Transmission Expansion and Modernisation of Ageing Grid Infrastructure:** One of the critical challenges in India's clean energy transition is the geographic mismatch between RE sources. These range from offshore wind to large-scale solar parks in desert regions and major load centres. Evacuating this power will require substantial investments in high-voltage transmission infrastructure to avoid grid congestion, transmission losses, and the under-utilisation of clean energy potential.

   India's power grid was originally designed around centralised generation from coal and hydro-based plants. As RE grows, particularly distributed resources such as rooftop solar (RTS), the grid must evolve to accommodate decentralised and bi-directional power flows.

b. **High AT&C Losses:** India's distribution networks continue to experience high levels of AT&C losses. AT&C losses stood at 16.12% in FY 2023-24 (Ministry of Power), implying that nearly one out of every six units of electricity generated is either lost within the system or remains unpaid due to factors such as electricity theft, faulty metering, and billing inefficiencies. These losses place significant strain on the financial health of DISCOMs, reducing their ability to invest in system maintenance, modernisation, and network expansion. While distribution-sector reforms are underway and several states have made progress, fixing distribution inefficiencies remains a slow and complex process.

c. **DISCOM Financial Stress:** The financial health of DISCOMs remains one of the most pressing challenges facing India's power sector. Persistent financial stress has significantly constrained DISCOM's capacity to invest in infrastructure upgrades and reforms essential for the clean energy transition. This, in turn, limits their ability to reliably procure and integrate RE.

   At the end of FY 2023, DISCOMs had accumulated losses of INR 6.48 lakh crore, while the total revenue of the electricity sector stood at INR 9.57 lakh crore. A significant portion of this revenue, INR 1.69 lakh crore (17.7%) was given as subsidies to agriculture and small domestic consumers. These subsidies are expected to exceed INR 2 lakh crore in FY 2024, adding further financial strain on the sector. In this context, at least in the medium term, India must prioritise low-carbon development pathways that are techno-economically viable and place limited additional strain on an already fragile distribution segment.

   Improving DISCOM performance will require a combination of tariff rationalisation and targeted financial support (Ministry of Power, 2024).

d. **Slow Modernisation of Distribution Grid:** While India has made significant progress in expanding power generation and transmission capacity and modernisation thereof, the pace of modernisation of distribution grid through the adoption of digital technologies has been considerably slower.

   An example of this is the RDSS Scheme, approximately 20.33 crore smart meters have been sanctioned for installation. However, as of January, 2026, about 5.44 crore meters have been installed nationwide (National Smart Grid Mission).

5.1.3 Cross-Cutting Innovation and Sustainability Challenges

a. **Domestic Manufacturing:** India's clean energy ambitions are growing rapidly, but the domestic supply chains required to support this growth are still developing. Manufacturing capacity for key technologies such as solar cells, PV modules, wind turbines and electrolysers has begun to scale up but remains below projected demand. Until this gap is bridged, India will continue to rely heavily on imports for critical components. This dependence increases project costs and exposes developers to risks arising from trade disruptions, foreign exchange volatility, and geopolitical uncertainty.

   The battery sector faces similar constraints. Key elements such as battery precursors, cells, and advanced chemistries are still predominantly sourced from other countries. While the government's PLI schemes and the National Critical Mineral Mission are steps in the right direction, building a robust and self-reliant clean energy supply chain should be a priority.

b. **Low R&D and Innovation Spending:** A critical but less visible challenge in India's clean energy transition is the relatively low level of investment in research and development (R&D), especially by the private sector. As of FY 2020-21, India's total R&D expenditure stood at 0.64% of GDP (Department of Science and Technology, 2023), significantly lower than the 2-3% observed in most advanced economies. In the clean energy domain, many Indian firms continue to operate with modest research budgets, resulting in greater reliance on adapting imported technologies rather than developing disruptive innovations domestically.

Although India has emerged as one of the world's largest solar markets, domestic innovation in areas such as solar cell and module design remains limited. Similarly, advanced battery chemistries and control systems are mostly imported. This weak R&D ecosystem constrains long-term competitiveness and slows progress in emerging areas such as long-duration energy storage, AI-enabled grid management, and next-generation hydrogen technologies. Strengthening R&D investment across both public and private sectors will be essential if India is to move beyond technology adoption and play a pro-active role in shaping the global clean energy innovation frontier. Schemes such as the Anusandhan National Research Foundation (ANRF) and Research, Development and Innovation (RDI) schemes should be leveraged to scale up domestic R&D.

c. **Cybersecurity Risks:** As digitalisation increases, the power sector becomes more exposed to cybersecurity risks. It has already emerged as a high-value target and is witnessing a gradual increase in cybersecurity threats. Recent global conflicts have involved nation/state sponsored threat actors and have highlighted the importance of ensuring adequate cybersecurity preparedness of power infrastructure.

With growing reliance on digital control and communication systems, strict compliance with cybersecurity protocols and good cyber hygiene practices is essential to safeguard grid integrity. In this context, in India, the establishment of a structured cybersecurity governance framework, followed by its continuous strengthening through an appropriate legal framework, will be essential to systematically safeguard the power sector from cybersecurity threats.

Therefore, a comprehensive Cybersecurity Framework for building and sustaining cyber resilience in the power sector, encompassing minimum cybersecurity requirements, a system of periodic cybersecurity assessments and compliance mechanisms, cybersecurity capacity building, and measures to address supply chain cybersecurity risks, needs to be adopted to build and sustain cyber resilience in the power sector.

5.1.4 Project Financing Challenges

a. **Capital-Intensive Nature of Clean Energy Projects:** Clean energy projects such as solar parks, wind farms, energy storage systems, and supporting grid infrastructure are inherently capital-intensive and require large upfront investments. While long-term returns are generally stable, the initial capital requirements can be significant, even for a large economy such as India. Domestic financing costs remain relatively high, and exposure to foreign exchange risk can further increase borrowing costs for projects with imported components.

Emerging technologies like offshore wind or green hydrogen are perceived as high-risk by lenders, resulting in conservative financing assumptions and a higher cost of capital. In this context, even modest project delays or policy changes can materially affect project viability. Unlocking the full potential of clean energy deployment will therefore require not only increased investment volumes but also a financing ecosystem that effectively de-risks new technologies and supports long-term, sustainable infrastructure investment.

b. **Inclusive Energy Transition:** Energy transition entails financing requirements beyond renewable energy deployment, including support for communities and regions dependent on coal-related activities. Investments are needed for job creation, reskilling, infrastructure development, and ecological restoration in coal-dependent regions. These challenges are compounded by potential revenue losses for governments arising from reduced coal-related taxes and royalties. In 2020-21, the central government derived approximately 34% of its revenues from the energy sector, while states' dependence on the energy sector stood at around 14%.

c. **Payment Delays:** Persistent payment delays by several state-owned DISCOMs continue to pose a major challenge for power sector financing (Ministry of Power). These delays increase revenue uncertainty for developers and reduce lender confidence, even in cases where long-term power purchase agreements (PPAs) are in place.

   While some states have introduced risk-mitigation mechanisms such as letters of credit and escrow arrangements, these measures are not yet uniformly implemented across the country.

5.1.5 Policy and Regulatory Challenges

a. **Policy Certainty:** The Central Government has taken significant steps to promote the renewable energy sector and enhance investor confidence. While variations in implementation across states such as tariff renegotiation and changes in auction guidelines have occasionally affected predictability, continued emphasis on prospective policy application will further strengthen confidence and support sustained investment in the sector.

b. **Institutional and Regulatory Landscape:**

   - **Fragmented regulatory landscape and weak enforcement:** Regulatory mandates in the power sector are spread across multiple institutions, including the Bureau of Energy Efficiency (BEE), the Central Electricity Regulatory Commission (CERC), and State Electricity Regulatory Commissions (SERCs). For example, co-existence of multiple instruments such as Renewable Purchase Obligations (RPOs) and Renewable Consumption Obligations (RCOs) under different administrative bodies dilutes regulatory effectiveness. Weak enforcement further undermines regulatory effectiveness. In practice, many SERCs do not enforce penalties for non-compliance.

   - **Uneven reform process among the states:** Implementation of reforms remains uneven across states. For example, while the Indian Electricity Grid Code (IEGC) and CEA's 2023 regulations[15] prescribe a Minimum Technical Load (MTL) of 55% or such other MTL for thermal units to support renewable energy

15 Flexible Operation of Coal-based Thermal Power Generating Units Regulations 2023

integration, most State Grid Codes continue to mandate higher thresholds, constraining system flexibility. There is therefore a need for uniform adoption and operationalisation of CEA's flexible operation regulations, including associated compensation and incentive mechanisms, by CERC, SERCs, and JERCs. Similar implementation gaps persist in the rollout of time-of-day tariffs, which, despite notification in several states, remain limited in practice.

c. **Technological and Market Uncertainties:** India's energy transition strategy relies on the deployment of multiple emerging technologies, including CCUS, coal gasification, green hydrogen, offshore wind, and battery energy storage systems (BESS). Many of these technologies remain costly or are still at an early stage of commercial development. These uncertainties are compounded by geopolitical risks, foreign exchange volatility, and continued dependence on imports for several critical technologies and components.

d. **Rigid Power Purchase Agreements:** India's power market is dominated by long-term Power Purchase Agreements (PPAs), which offer limited operational and contractual flexibility. These rigidities constrain the integration of renewable energy, particularly given the variable and intermittent nature of solar and wind generation.

e. **Regulatory conflicts in Carbon Pricing:** India is introducing carbon pricing through the Carbon Credit Trading Scheme (CCTS); however, the power sector is currently excluded from its scope. If the power sector is brought under the carbon market in the future, overlaps with existing instruments such as RPOs could create regulatory conflicts and compliance complexities. Any inclusion of the power sector will therefore need to carefully account for cost implications, particularly for end consumers.

f. **Divergent Union-State Priorities:** Differences in priorities between the Union and state governments also pose challenges for the energy transition. While the Union government emphasises energy security and international climate commitments, state governments often prioritise local employment generation and revenue stability.

5.2 OPPORTUNITIES FOR A CLEAN ENERGY FUTURE

5.2.1 Generation Sector Opportunities

a. **Unleashing India's Solar and Wind Potential:** India's geography provides a strong foundation for scaling clean energy. Abundant solar resources and long, windy coastlines position the country to become a global renewable energy leader. With over 133 GW of solar capacity and 54 GW of wind capacity installed as of Nov 2025, India has already made substantial progress and retains significant headroom for further expansion.

   Hybrid renewable energy projects that combine solar and wind on the same site present a particularly promising opportunity, as they help smooth generation variability. The government is actively supporting the deployment of such hybrid projects through dedicated guidelines and policy support.

b. **Distributed Generation and Rooftop Solar Expansion:** India is increasingly moving towards a decentralised energy paradigm. Rooftop solar systems across homes, offices, and factories are emerging as an effective solution to land acquisition constraints, reducing pressure on transmission networks and enabling consumers to generate power closer to the point of use. Under the PM Surya Ghar scheme, more than 10 million households applied for rooftop solar systems within the first month of its launch.

Beyond households, programmes such as PM-KUSUM are supporting the solarisation of agricultural pumps and feeders, improving the reliability of power supply for farmers while reducing diesel and grid dependence. From the perspective of financially stressed DISCOMs, distributed solar also offers a strategic benefit by lowering subsidy burdens, particularly for agricultural and low-income domestic consumers.

c. **India's Global Leadership in Clean Energy:** Through the **International Solar Alliance (ISA)**, India has positioned itself as a global leader in advancing solar energy adoption and international cooperation. Building on this foundation, India is spearheading the **One Sun, One World, One Grid (OSOWOG)** initiative, which aims to interconnect solar-rich regions across countries to enable cross-border exchange of clean electricity and enhance global energy security.

   India is also strengthening regional electricity trade with neighbouring countries such as Nepal, Bhutan, and Bangladesh, contributing to improved grid stability, optimal resource utilisation, and deeper regional cooperation.

d. **Scaling Domestic Clean-Technology Manufacturing:** India's Make in India initiative is beginning to reshape the renewable energy landscape. Backed by targeted manufacturing incentives like the PLI scheme, the country is rapidly expanding its industrial base for clean energy components, including solar PV modules, wind turbine blades, batteries and electrolysers. Solar module manufacturing capacity is projected to increase significantly by 2030, with parallel momentum emerging in battery manufacturing.

   This scale-up is reducing import dependence, lowering equipment costs, and generating employment across the value chain. At the same time, leading renewable energy developers are increasingly entering strategic partnerships with manufacturers to secure supply chains. The convergence of clean energy deployment and industrial growth is contributing to the development of a more resilient and self-reliant low-carbon power ecosystem.

5.2.2 Transmission and Distribution Sector Opportunities:

a. **Grid Expansion and Green Energy Corridors:** Transmission infrastructure remains a critical enabler of India's clean energy transition, and significant investments are underway for reliable evacuation and utilisation of the clean energy. High-capacity inter-state and inter-regional transmission systems are being implemented to evacuate renewable power from resource-rich states such as Rajasthan, Gujarat, Karnataka, Andhra Pradesh, Tamil Nadu, etc. to major demand centres across the country. Under the Green Energy Corridor Scheme, a few important inter-state transmission corridors are being implemented, and state utilities are implementing intra-state transmission system for integration and reliable evacuation of renewable energy.

b. **Smart Grid and Digitalisation:** Grid modernisation efforts under the Revamped Distribution Sector Scheme (RDSS) and the National Smart Grid Mission (NSGM) are strengthening system reliability through the deployment of smart meters, automation, and digital technologies. Advanced analytics, improved forecasting tools, and the use of artificial intelligence are enhancing the integration of variable renewable energy while supporting more efficient grid operations.

c. **Strengthening market mechanism:**

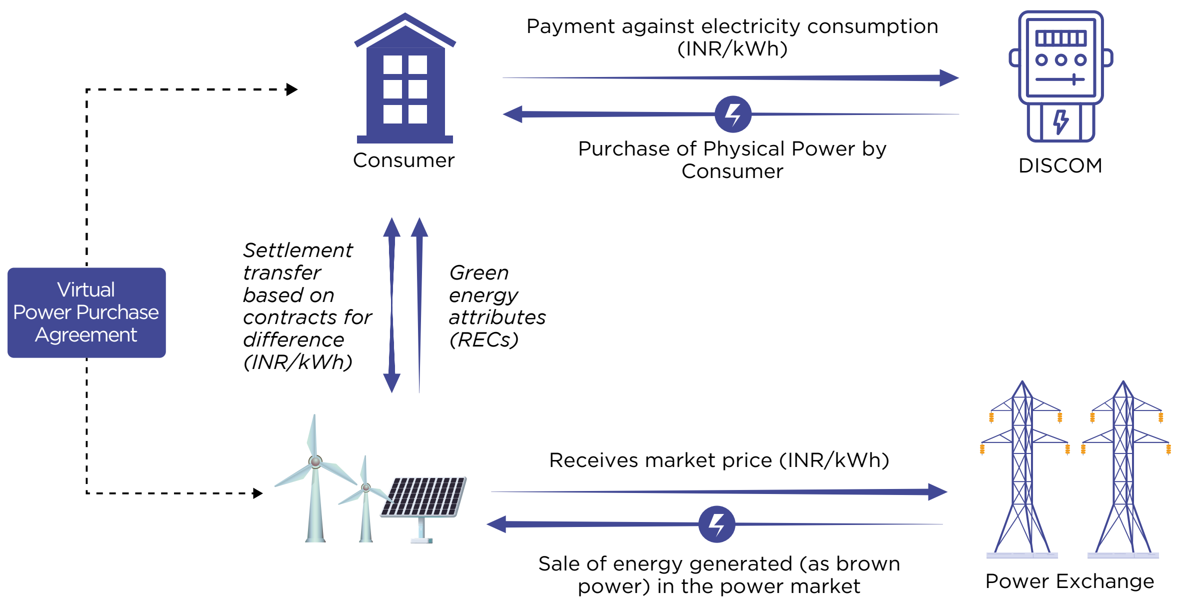


Figure 5.1: Schematic of Virtual Power Purchase Agreement (VPPA)

- **Virtual Power Purchase Agreements (VPPAs)** are financial contracts between renewable energy generators and corporate buyers, under which electricity is sold into the grid while buyers receive renewable energy certificates and price certainty without taking physical delivery of power (see Figure 5.1). VPPAs enable RE adoption without disrupting existing power purchase structures, benefiting corporates, generators, and DISCOMs. However, clear policies and regulatory frameworks are essential for large-scale adoption in India.
- **Local Electricity Markets (LEMs)** enable direct trading between local electricity producers—such as rooftop solar generators—and nearby consumers. These markets can improve the utilisation of surplus electricity, reduce grid congestion, stabilise voltage, and support more efficient local balancing of supply and demand.
- **Electricity Derivatives Markets:** Electricity derivatives can support advanced risk hedging and forward contracting in the power sector. As India transitions towards a renewables-heavy grid, such instruments can help manage price volatility and improve financial planning across the value chain.
- **Virtual Energy Storage:** Aggregating distributed and behind-the-meter resources, such as electric vehicle batteries, stationary batteries, flexible loads, and thermal storage, can deliver many of the grid-balancing and peak-shaving benefits of physical storage at lower system cost. ToD, dynamic pricing, and appropriate grid

codes can enable consumer participation, while aggregators and digital platforms can coordinate these resources to provide ancillary services, integrate higher shares of renewables, and enhance overall grid resilience.

5.2.3 Cross-Cutting Innovation and Sustainability Opportunities

a. **Circular Economy: Recycling of Solar Panels and Batteries:** Solar panels and batteries contain valuable materials such as silicon, copper, lithium, and rare metals, which should not be disposed of in landfills at their end of their useful life. Recognising this, the government has amended e-waste rules to include solar PV modules and notified the Battery Waste Management Rules, 2022. These regulations place extended producer responsibility on manufacturers, requiring them to manage the full life cycle of their products.

   At the implementation level, recycling enterprises are beginning to emerge, with several firms establishing facilities to recover materials such as silver, copper, and silicon from end-of-life solar modules. In the case of batteries, particularly electric vehicle batteries, the regulatory framework mandates collection and recycling rather than disposal. Over time, effective recycling systems can reduce dependence on imported critical minerals, minimise environmental impacts, and create new green employment opportunities.

   In this context, NITI Aayog has played a key enabling role by releasing three reports on enhancing the circular economy, covering End-of-Life Vehicles (ELVs), Waste Tyres, E-waste, and Lithium-ion-Batteries. These reports identify key ecosystem challenges and recommend measures for infrastructure development, sector formalisation, strengthening the Extended Producer Responsibility (EPR) framework, and enhancing revenue generation.

b. **Skilling and Workforce Development:** The clean energy transition is generating opportunities across manufacturing, construction, transport, research, and services. National initiatives such as Skill India and PM-KUSUM are supporting workforce development, especially in rural areas, while reskilling programmes are facilitating the transition of workers from traditional sectors such as coal.

   With the growth of clean energy industries, startups, and government-led sustainability missions, India has a strong opportunity to translate its energy transition into broad-based employment generation, while building a workforce aligned with future energy system needs.

c. **Clean Tech Startup Boom:** India's startup ecosystem is increasingly contributing to clean energy innovation. From battery-swapping networks and smart inverters to agrivoltaics solutions that blend farming with solar generation, climate-tech entrepreneurs are finding creative ways to tackle the energy transition.

d. **International and Academic Partnerships:** India's clean energy transition is being supported by international and academic collaboration. Bilateral partnerships with countries such as the U.S., Japan, and members of the European Union are facilitating joint research, technology development, and knowledge exchange in areas including advanced battery chemistries and second-life energy storage.

India's participation in initiatives such as Mission Innovation further strengthens access to global research networks and funding. These collaborations help reduce innovation risks, shorten learning curves, and support the development of domestic capabilities while ensuring alignment with global best practices.

5.2.4 Project Financing Opportunities

a. **Green Finance and Investment Opportunities:** India's transition to a low-carbon economy has unlocked significant investment opportunities. This shift is drawing increasing interest from both domestic and international investors through instruments such as green bonds, sustainability-linked loans, and climate-focused funds. This will need to be leveraged through better project design and financing instruments.

5.2.5 Policy and Regulatory Opportunities

a. **Stronger Centre-State Collaboration:** Improved coordination between the Union and state governments presents an important opportunity to accelerate India's energy transition. New institutional platforms are emerging to support more effective collaboration. The Cabinet Committee on Economic Affairs (CCEA) has adopted a more active role in reviewing renewable energy targets and inter-ministerial alignment. Annual conferences of power ministers are increasingly focused on actionable outcomes.

   At the operational level, renewable-rich states such as Gujarat and Tamil Nadu are entering into power purchase arrangements with industrial states, generating mutual benefits. The Central Electricity Authority (CEA) is also working more closely with State Electricity Regulatory Commissions to improve coordination in transmission planning across state boundaries.

6

KEY SUGGESTIONS

6

Key Suggestions

Achieving net-zero emissions by 2070 will require India to fundamentally transform its power sector, which accounted for 39.4% of the country's total GHG emissions in 2020 (MoEFCC, 2024). This transformation will require a gradual shift away from fossil fuel-based generation towards cleaner sources such as solar, wind, nuclear, and other low-carbon alternatives.

The transition must be carefully planned and supported by robust policy frameworks to ensure that it remains reliable, affordable, and inclusive. The following section presents key Suggestions across various thematic areas:

(i) Generation Sector

(ii) Transmission and Distribution

(iii) Cross-Cutting

(iv) Policy and Regulatory

(v) Project Financing

Suggestions for Power Sector Low-Carbon Transition

6.1 GENERATION SECTOR

a. **Promote Adoption of Clean and Flexible Nuclear Power**

(i) **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.

(ii) **Enabling Legislative Framework to Encourage Private Investment in Nuclear Power:** Public-Private Partnership (PPP) models may be explored to attract private investment into nuclear power generation. This can reduce the financial burden on the government and accelerate the deployment of clean baseload power. In this context, the Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Act 2025, 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. The Act emphasises fuller utilisation of indigenous nuclear resources, enables active participation of both public and private sectors, and positions India as a credible contributor to the global nuclear energy ecosystem.

(iii) **Green Bonds for Nuclear Projects:** Nuclear energy may be made eligible for green bond financing, given that it is a low-carbon source. This can help to attract global climate finance and support funding for new nuclear projects.

b. **Scale up Co-located Solar–Wind Hybrid Plants with Storage:** India should accelerate the development of co-located solar-wind parks integrated with battery storage to improve land-use efficiency, enhance grid utilisation, reduce curtailment, and deliver a firmer clean power supply. Solar generation during the day and stronger wind output in the evening and early morning complement each other, resulting in a more stable renewable energy profile. Battery storage further enhances reliability by storing surplus generation and meeting peak demand.

To enable this transition, 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. The Solar Energy Corporation of India (SECI) and state DISCOMs may issue coordinated tenders supported by standardised PPAs and robust payment security mechanisms.

c. **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.

To scale deployment, 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. Similar approaches may be extended to MSMEs and public buildings. In parallel, 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.

d. **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), ramp rates, and start-up/shutdown procedures. Lower MTLs and higher ramping capabilities enhance the system's ability to absorb higher RE generation during solar peak periods while maintaining grid stability. However, implementation of such a requirement must account for unit-specific technical retrofits and operators' training for sustained low-load operation. Promotion of flexibility entails the following measures:

(i) CEA, in collaboration with relevant agencies, may implement and monitor a phased flexibility programme to achieve lower minimum load operation. The CEA has recently notified a flexibility plan for operating coal plants at 40% MTL (VGBE PowerTech, 2023). This plan needs to be implemented by RLDCs/SLDCs following a comprehensive analysis of the thermal fleet operating under their jurisdiction.

(ii) To incentivise flexible operation, CERC/SERCs need to operationalise and extend compensation frameworks for flexible operation and enable market-based monetisation of flexibility.

e. **Repurposing Retired Coal Plants as Clean Energy Hubs:** Ministry of Power (MoP), in coordination with Central Electricity Authority (CEA), needs to prepare a structured plan to retire old and inefficient thermal power plants, particularly units over 25 years old with low efficiency and high emissions. Once retired, these sites can be repurposed as clean energy hubs by leveraging existing land, water availability and transmission infrastructure.

f. **Repower Ageing Wind and Solar units:** Many older wind turbines and solar installations are based on outdated technologies and operate at lower efficiencies. Replacing these assets with newer, more efficient ones, such as higher hub height wind turbines or higher efficiency solar modules on the same land parcels can significantly increase clean energy output while minimising incremental land and grid infrastructure requirements.

To enable this, MNRE, in collaboration with state DISCOMs, may identify potential repowering assets. State DISCOMs in partnership with project developers should also establish repowering-friendly PPA pathways and incentivise incremental generation through clear metering and settlement mechanisms for upgraded capacity.

g. **VGF Support for Promising Clean Energy and Storage Technologies:** A dedicated Viability Gap Funding (VGF) scheme may be developed to accelerate the deployment of first-of-a-kind and emerging clean energy technologies, including advanced solar such as Concentrated Solar Power (CSP), as well as long-duration storage solutions like Pumped Storage Projects. CSP offers valuable system benefits, including inherent thermal storage capability, dispatchable renewable generation, and improved evening and peak-hour supply, thereby enhancing grid flexibility and reducing reliance on fossil-based peaking power. Similarly, pumped storage provides critical services such as flexibility, inertia, reactive power support, and Fault Ride Through (FRT) capability, which are essential for large-scale integration of renewable energy.

The VGF framework should be technology-agnostic and targeted toward projects that demonstrate strong potential for cost reduction, grid stability, and domestic value creation. Such support would help de-risk early investments, enable commercialisation of next-generation solutions, and strengthen India's transition to a resilient, low-carbon power system.

h. **Promote Storage through Market-Based Incentives and Competitive Procurement (Across Technologies):** To enable a flexible and renewable-rich power system, India should prioritise market-driven mechanisms that encourage cost-effective deployment of energy storage. Appropriate price signals, such as time-of-day tariffs, ancillary service markets, and capacity remuneration mechanisms, can incentivise investment in both short-duration solutions like batteries and long-duration options such as pumped hydro and emerging hydrogen-based storage.

Storage should be integrated into national and state resource adequacy planning and procured through technology-agnostic, competitive tenders that value system services including flexibility, peak support, and reliability. Strengthening domestic battery manufacturing, streamlining regulatory approvals, and expediting pumped hydro development will further support least-cost deployment. A market-oriented approach will help deliver round-the-clock clean energy while enhancing grid resilience.

6.2 TRANSMISSION AND DISTRIBUTION SECTOR

a. **Build Infrastructure for Renewable Power Evacuation:** As India accelerates its RE deployment, the timely development of supporting transmission infrastructure is essential to ensure that generation capacity does not outpace evacuation readiness. Renewable-rich states such as Rajasthan, Gujarat, Tamil Nadu, Andhra Pradesh, Karnataka, etc., require robust intra-state and inter-state transmission systems to efficiently deliver power to demand centres.

   Transmission schemes associated with RE generation must be prioritised and fast-tracked to align with the commissioning timelines of upcoming solar and wind projects. In parallel, states should identify and allocate land for RE zones and work closely with central agencies to plan shared transmission infrastructure. A coordinated approach that aligns generation and transmission planning will be critical to enabling the reliable, affordable, and large-scale integration of renewables into the grid. Further, States should plan and implement intra-state transmission network commensurate with load growth and expansion of Inter-State Transmission System (ISTS).

b. **Strengthen Cross-Border Transmission Networks:** Strengthening cross-border transmission infrastructure is critical for enhancing regional power system resilience and advancing India's clean energy goals. As domestic renewable capacity scales up and electricity demand continues to grow, regional interconnections enable the import of low-cost hydropower from Bhutan and Nepal, facilitate the export of surplus solar and wind power during peak generation periods, and provide additional flexibility through cross-border balancing.

   These efforts align with India's broader vision under the One Sun One World One Grid (OSOWOG) initiative. To realise this potential, India should fast-track high-capacity interconnection corridors, jointly harmonise grid codes and operating procedures, streamline regulatory clearances, and promote planning and investment in transmission infrastructure. A well-integrated regional grid can strengthen energy security, unlock clean energy trade, and position India as a leader in South Asia's energy transition.

c. **Accelerate Smart-Grid Digitalisation:** 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.

Special focus must be placed on building a grid that is not only smart but also secure and resilient: capable of isolating faults, withstanding cyberattacks and recovering quickly from disruptions. Fast-tracking these interventions will be key to building a reliable, responsive, and future-ready grid.

d. **Enable Peer-to-Peer Energy Trading**: With the growing adoption of rooftop solar and behind-the-meter storage, Peer-to-Peer (P2P) energy trading offers a new opportunity to improve local energy access and system efficiency. Enabling consumers to act as prosumers and trade surplus power within communities can reduce grid stress and accelerate clean energy uptake.

   This will require a supporting digital public infrastructure for energy, building on India's emerging Energy Stack, to enable interoperable smart meter data, consent-based data sharing, and secure, low-cost transactional rails for P2P energy markets.

   Regulatory sandboxes should be used to pilot new business models and digital trading platforms in a controlled environment, with lessons from these pilots informing the development of a national framework for distributed energy markets.

e. **Reduce AT&C Losses:** Reducing AT&C losses remains central to improving the financial health of DISCOMs and ensuring a reliable power supply. This will require a focused push on feeder segregation, distribution network upgrades, and a consumer-centric rollout of smart metering. Smart and prepaid meters should be deployed in a manner that delivers clear benefits to consumers, such as accurate billing, better consumption insights and flexible payment options, thereby strengthening acceptance and participation while reducing theft and billing inefficiencies.

f. **Improving the Financial Viability of DISCOMs:** Improving the financial viability of DISCOMs is critical to unlocking sustained investment in grid modernisation and enabling the power sector transition. MoP may consider designing a one-time DISCOM debt takeover and restructuring scheme, with central support provided on a conditional basis. Such support should be explicitly linked to the adoption of credible and irreversible structural reforms. These measures should be supported by clearly defined, time-bound milestones for governance improvements and efficiency gains. 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.

g. **Feeder Separation for 24x7 Reliable and Quality Power Supply:** To ensure all consumer categories receive, high quality reliable electricity supply, feeder segregation is critical. Segregating agricultural and non-agricultural rural feeders has already enabled several states to improve load management, enhance supply to rural households and small industries, and achieve more accurate accounting of agricultural subsidies announced by state governments (World Bank, 2013). 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.

h. **Enable Competition and Active System Management in Distribution:** This will require amendments to the Electricity Act (2003), to allow multiple distribution licensees to supply consumers over the incumbent utility's network through mandatory, non-discriminatory open access. This would separate the "wires" and "supply" functions, expand consumer choice and avoid duplicative infrastructure. In parallel, the introduction of Distribution System Operators (DSOs) for real-time management of the distribution network may be considered. DSOs would be responsible for actively managing the low-voltage networks, integrating distributed energy resources, including virtual storage such as smart loads and vehicle-to-grid systems, and procuring local flexibility.

6.3 CROSS-CUTTING SUSTAINABILITY AND INNOVATION

a. **Forecasting and Scheduling:** As India's RE capacity grows, accurate forecasting and scheduling will be critical to maintaining grid stability and ensuring efficient dispatch. Advanced tools based on Artificial Intelligence (AI), machine learning, and high-resolution weather models should be more widely deployed for both demand and generation forecasting, particularly in RE-rich states. To strengthen forecasting and scheduling, the following measures may be considered:

   (i) Regulators may mandate high-accuracy forecasting for all grid-connected RE plants, with clear performance benchmarks and penalties for persistent deviations.

   (ii) At the national level, MNRE may propose a standardised methodology and dashboard to aggregate forecasts, enabling improved planning and real-time system-level decision-making.

b. **Strengthen Domestic Manufacturing & Circularity:** To ensure long-term self-reliance and global competitiveness in clean energy, a robust clean tech manufacturing ecosystem needs to be developed. While the PLI schemes have successfully catalysed initial investments, the next phase should focus on strengthening domestic value chains, fostering collaborative R&D, and improving access to affordable, long-term capital.

   In this context, the National Manufacturing Mission offers a timely opportunity to drive scale, innovation, and coordination across the sector (Council for International Economic Understanding). Their effectiveness will depend on aligning manufacturing targets with projected energy demand, supported by stable procurement pipelines and clear, long-term policy signals.

   In parallel, the MoEFCC, in collaboration with MNRE, may operationalise traceability and recycling standards for solar PV modules and battery systems under the updated waste management rules (PIB, 2023). This would help to create an assured end-of-life feedstock pipeline and support the development of a circular cleantech economy.

c. **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.

Periodic compliance assessments should be instituted to ensure continuous adherence to strengthen the resilience of the power system against evolving cyber threats.

d. **Streamlining Land Acquisition:** Faster land acquisition is essential to meet India's growing renewable and transmission needs. This requires coordinated planning between central and state governments to identify and pre-approve land parcels for energy projects. Digitising land records and setting up single-window systems for clearances can greatly reduce delays. At the same time, innovative models like land leasing or pooling may be explored.

6.4 POLICY AND REGULATORY

a. **Move Towards Cost-Reflective Tariffs:** India's electricity tariff structure is complex and varies across states, marked by multiple slabs, non-uniform pricing, and heavy cross-subsidisation. This results in inefficiencies, limited transparency, and financial stress for DISCOMs. Tariffs should therefore be gradually rationalised to better reflect the true cost of supply, while continuing to protect low-income households through targeted subsidies.

b. **Scaling out Time-Based Electricity Pricing (ToD/ToU):** Dynamic pricing mechanisms such as ToD and ToU tariffs encourage consumers to shift electricity consumption to off-peak periods. This promotes demand response, reduces peak load stress on the grid, and facilitates improved integration of VRE.

c. **Set Feeder-Level Loss Reduction Targets:** Regulators may encourage DISCOMs to track and report technical and commercial losses separately at the feeder level. Clear and time-bound targets, particularly for high-loss feeders, can be established to enable targeted interventions and improve accountability in performance monitoring.

d. **Strict Enforcement of Clean Energy Mandates:** Effective implementation of Renewable Consumption Obligations (RCOs) and other clean energy mandates should be ensured by clearly defining compliance pathways, monitoring mechanisms, and penalties for non-compliance across all obligated entities. Stronger Centre–State coordination will be essential to harmonise targets, avoid overlapping or conflicting mandates, and ensure consistent enforcement.

e. **Shift Towards Market-Based Renewable Energy (RE) Models:** At present, power capacity is largely added through long-term Power Purchase Agreements (PPAs) or Power Sale Agreements (PSAs). To facilitate sustainable scaling of power capacity, greater reliance on market-based mechanisms such as green markets, power exchanges, and short-term bilateral trading may be encouraged. These approaches enhance flexibility, attract private participation, and reduce dependence on centralised procurement. This shift can be supported through the following measures:

   (i) **Implement Ancillary Service and Capacity Markets:** Accelerate the rollout of a comprehensive ancillary service market and establish a formal capacity market to ensure adequate reserves, system flexibility, and long-term resource adequacy. These markets incentivise fast-response resources such as storage, demand response, and flexible generation, while providing DISCOMs and investors with clearer price signals and revenue streams.

(ii) **Strengthen Open Access Rules:** Open access enables large consumers to competitively procure RE across states and regions. Simplifying the approval process, ensuring non-discriminatory wheeling and surcharge structures and providing long-term regulatory certainty can reduce transaction costs and accelerate RE uptake.

f. **Make Rooftop Solar Mandatory for Government Buildings:** Decentralised Renewable Energy (DRE) systems such as Rooftop Solar (RTS) offer significant benefits by reducing grid dependence, minimising technical losses, and lowering infrastructure costs. To accelerate deployment, installation of RTS systems may be made mandatory for all public buildings, using models such as Renewable Energy Service Company (RESCO) to minimise upfront investment. In addition, replacing diesel generators with battery storage systems integrated with RTS should be strongly encouraged.

g. **Capacity Building for a Future-Ready Power Sector:** As India's power sector evolves with increasing RE integration, digitalisation, and advanced grid technologies, continuous capacity building will be essential. There is a need to institutionalise regular and specialised training and upskilling programmes for power sector professionals including DISCOM personnel, grid operators, and regulatory staff, especially in areas like smart grid operations, cybersecurity, RE and demand forecasting, and storage integration. Collaborations with premier technical institutions, public-private training partnerships, and the development of online modular courses can make capacity building more accessible and scalable. Regulators may also encourage DISCOMs to allocate dedicated funds and set annual targets for workforce training.

h. **Establish a National Grid Resilience Task Force and Mandate State-Level IRP:** A National Grid Resilience Task Force may be established, comprising, CEA, Grid-India, MNRE, and state utilities, to provide strategic direction on managing variability, reliability and stability in a high-RE system. In parallel, states should carry out Resource Adequacy Studies to holistically assess conventional capacity, RE capacity, storage requirements, flexibility resources, including demand response, and associated transmission and distribution build-out. Regularly updated Resource Adequacy Plans will help align investments and minimise the risk of stranded assets.

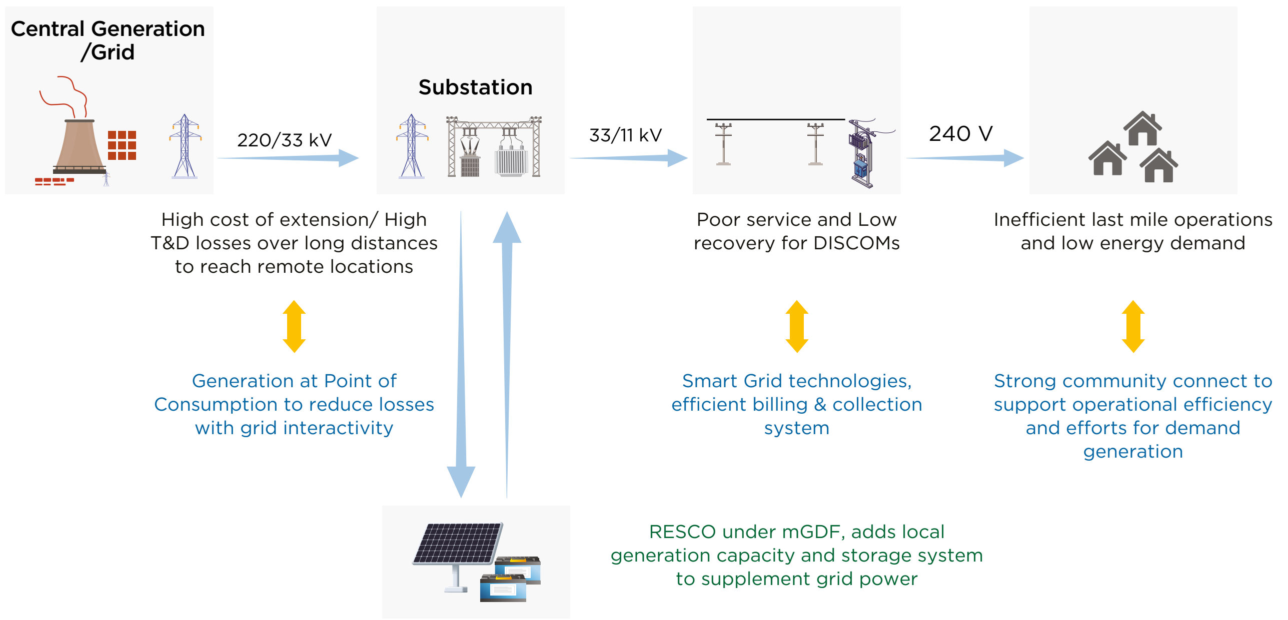
6.5 PROJECT FINANCING

a. **Mobilise Concessional and Blended Climate Finance:** India's clean energy transition will require sustained access to affordable, long-term capital across the energy value chain. To enable this, concessional finance from multilateral development banks and global climate funds should be strategically leveraged to support large-scale infrastructure investments, including transmission networks, energy storage, and RE projects.

Structuring integrated projects such as solar-plus-storage or grid-modernisation bundles can help attract blended finance and reduce project risk. These efforts may be complemented by financial innovations such as securitisation of future revenues and the use of credit enhancement instruments to unlock private sector participation and lower the overall cost of capital.

b. **New Franchise Models in Power Distribution:** Introducing alternative franchise models (see Figure 6.1) for power distribution in cities and towns can improve operational efficiency, service quality, and innovation, while ensuring consumer accountability.

GDF is a PPP approach that allows DISCOMs to reduce financial losses, allows private RESCOs to service loss making areas by integrating renewables, and enables 24/7 cleaner power for customers



Benefit for DISCOMs	Benefit for private RESCOs	Benefit for Community
• Outsourcing of loss-making areas • 100% recovery of input power • Enhanced grid decarbonisation • Improved customer satisfaction (C-SAT)	• Commercially viable business model in rural/peri-urban areas • Value added services to large customer base • Integrate DRE & smart grid technologies	• 24/7 reliable power • Better customer service • Local Green Job creation • No increase in tariff • Improved quality of life

Figure 6.1: Generation and Distribution Franchisee (GDF)

ANNEXURES

Annexure A: Recent Interventions to promote Renewable Energy uptake

Category	Recent Interventions
Solar	• Under the PLI scheme, the GOI has announced INR 19,500 crores to incentivise the manufacturing of domestic solar PV modules. • PM-Surya Ghar: Muft Bijli Yojana released with a total outlay of INR 75,021 Cr for installing RTS for one crore households. The scheme provides a Central Financial Assistance (CFA) of INR 30,000 for a 1 kW RTS system, INR 60,000 for a 2kW RTS system, and INR 78,000 for a 3kW RTS system. • The inter-state transmission charges are waived for 25 years for the projects being commissioned before 30th June 2025, with graded transmission charges thereafter. • The updated RPO compliance supports a specific other RE integration (which includes solar) of up to 34.02% of the electricity purchased by DISCOMs/states till the year 2029-30. • PM KUSUM scheme has been extended till March 2026 to install agriculture pump sets with upto; 15 HP in selected areas.
Wind	• Reverse auctions have been scrapped for wind projects. A traditional two-part (technical and financial) bid system has been put in place. • To support offshore wind, SECI will invite bids for up to 4GW to set up offshore wind plants off the coast of Tamil Nadu and Gujarat. • The ISTS charges are waived for 25 years for the onshore projects being commissioned before 30th June 2025 and for offshore projects on or before 31st December 2032. • The updated RPO compliance supports wind integration of up to 3.48% of the electricity purchased by DISCOMs/states till the year 2029-30. • The National Repowering & Life Extension Policy for Wind Power Projects-2023, for wind power projects, is released for the optimum utilisation of wind energy resources by maximising energy (kWh) yield per sq. km of the wind project areas. • GoI has decided to invite bids for 50 GW of RE annually, which includes up to 10 GW of wind capacity.

Energy Storage	• The Ministry of Power has released the guidelines for the development of PSP with the target of 26.7 GW of PSP and 47.2 GW of BESS to integrate with RE capacity till 2032. • PLI scheme unveiled for setting up 50 GWh ACC battery storage with an outlay of INR 18,100 crores. • Under the Waste Management Rules 2022, the disposal of waste batteries in landfills and incineration is prohibited and the recycling of waste batteries is made mandatory. • CERC, under RRAS regulation, has allowed the use of energy storage in secondary and tertiary ancillary support. • The Energy Storage Obligation of DISCOMs is pegged at 4.0% up to 2029-30. This obligation shall be considered fulfilled only when at least 85% of the total energy stored in the Energy Storage System (ESS), on an annual basis, is procured from renewable energy sources. • Under the aegis of MNRE, SECI has successfully commissioned India's largest BESS plant, featuring a 40 MW/120 MWh BESS alongside a solar PV plant of 152 MWh, located in Rajnandgaon, Chhattisgarh.
Green Hydrogen (H_2)	• The National Green Hydrogen Mission (NGHM) was approved by the Cabinet in January 2023. The mission aims to meet the target of 5 million metric tonnes of green hydrogen production by 2030. The initial outlay for the Mission will be INR 19,744 crores. • MNRE has released the scheme guidelines for the implementation of pilot projects for the use of Green Hydrogen in the shipping, steel, and transport sectors under the NGHM. • MOP has extended the waiver of ISTS charges from 30th June 2025 to 31st December 2030. • Indian Railways to run 35 Hydrogen trains under "Hydrogen for Heritage" at an estimated cost of INR 80 crores per train and ground infrastructure of INR 70 crores per route on various heritage/hill routes. • Jindal Stainless Ltd., in collaboration with Hygenco, commissioned India's 1st green hydrogen plant in the stainless steel sector at Hisar, Haryana, which aims to reduce CO_2 emissions by 2,700 metric tonnes per annum.

Annexure B: State/ UT-wise Renewable Energy Potential

State	Solar (GW)	Large Hydro (GW)	Wind (GW)	Small Hydro (GW)	Pumped Storage (GW)	Bio Power (GW)
Andaman & Nicobar	-	0.00	1.25	0.01	0	0.018
Andhra Pradesh	704.88	2.60	123.34	0.41	26.42	2.279
Arunachal Pradesh	2.36	50.39	0.25	2.06	0.66	0.018
Assam	77.14	0.64	0.46	0.20	0.32	0.322
Bihar	134.57	0.13	4.02	0.53	0	1.311
Chandigarh	0.2	0.00	0.00	0.00	0	-
Chhattisgarh	312.41	1.31	2.75	1.10	8.525	0.354
Dadra & Nagar Haveli & Daman & Diu	1.64	0.00	0.02	0.00	0	0.002
Delhi	2.38	0.00	0.00	0.00	0	-
Goa	11.48	0.00	0.01	0.00	0	0.033
Gujarat	1005.7	0.55	180.79	0.20	7.7	3.193
Haryana	32.87	0.00	0.59	0.11	0	1.715
Himachal Pradesh	66.35	18.31	0.24	3.46	7.26	0.07
Jammu & Kashmir	38.98	12.26	0.00	1.31	0	0.083
Jharkhand	152.36	0.30	0.02	0.23	1.5	0.146
Karnataka	739.36	4.41	169.25	3.73	7.6	3.556
Kerala	20.2	2.47	2.62	0.65	1.2	0.778
Ladakh	27.3	0.71	0.00	0.40	0	-
Lakshdweep	-	0.00	0.03	0.00	8.56	0.001
Madhya Pradesh	938.05	2.82	55.42	0.82	43.405	2.516
Maharashtra	1303.79	3.14	173.87	0.79	0	6.547
Manipur	8.87	0.62	0.00	0.10	0	0.062
Meghalaya	44.22	2.03	0.06	0.23	5.55	0.069
Mizoram	0.95	1.93	0.00	0.17	0	0.003
Nagaland	1.14	0.33	0.00	0.18	5.075	0.054

State	Solar (GW)	Large Hydro (GW)	Wind (GW)	Small Hydro (GW)	Pumped Storage (GW)	Bio Power (GW)
Odisha	400.14	2.83	12.13	0.29	0	0.299
Puducherry	0.24	0.00	0.41	0.00	0	0.005
Punjab	49.28	1.30	0.43	0.58	9.2	3.436
Rajasthan	2457.82	0.41	284.25	0.05	0	1.3
Sikkim	1.54	6.05	0.00	0.27	16.5	0.005
Tamil Nadu	499.24	1.79	95.11	0.60	8.755	2.199
Telangana	439.6	1.30	54.72	0.10	0	1.795
Tripura	23.22	0.00	0.00	0.05	16.62	0.034
Uttar Pradesh	666.75	0.50	0.51	0.46	1	7.726
Uttarakhand	704.88	13.48	0.05	1.66	5.5	0.308
West Bengal	2.36	0.81	1.28	0.39	0	1.742
Others	0.00					0.284
Total	**10,872.28**	**133.41**	**1163.86**	**21.13**	**181.35**	**42.26**

Source: *ICED & PIB*

Note: *The solar potential is provided by stakeholder consultations conducted by the Working Group on the Power Sector*

Annexure C: Assumptions on Land-Use Factor per MW of Power

Land-use factor (Acres per MW)			
	2030	**2050**	**2070**
Coal Power Plant	0.80	0.80	0.80
Gas Power Plant	0.12	0.12	0.12
Nuclear Power Plant	0.60	0.60	0.60
Large Hydro Power Plant	4.99	4.99	4.99
Solar PV Plant	2.97	1.98	1.98
On-shore wind Power Plant	3.46	3.46	3.46
Biomass Power Plant	5.98	5.98	5.98

Annexure D: Assumptions on Water-Use Factor per Unit of Output

Water-Use Factor	
Coal Power Plant (MCM/Mtoe)	40.65
Gas Power Plant (MCM/Mtoe)	14.30
Nuclear Power Plant (MCM/Mtoe)	44.43
Green Hydrogen Plant (litre/kgH_2 or MCM/Mt)	25

Annexure E: Weighted Average Emissions Factor of Grid Electricity $kgCO_2/kWh$

FY	Total CO_2 Emissions (Million Tonnes)	Net Generation (BU) Conventional	RE Generation (BU)	Total Net Electricity Generation (BU)	Weighted Average Emissions Factor of Grid Electricity (Including RE) tCO_2/MWh
2013-14	727.4	886.77	53.06	939.83	0.774
2014-15	805.4	972.04	61.72	1033.76	0.779
2015-16	846.3	1027.03	65.78	1092.81	0.774
2016-17	888.34	1072.84	81.55	1154.39	0.770
2017-18	922.18	1121.57	101.84	1223.41	0.754
2018-19	960.9	1165.16	126.76	1291.92	0.744
2019-20	928.14	1162.97	138.34	1301.31	0.713
2020-21	910.02	1147.52	147.25	1294.77	0.703
2021-22	1002.01	1230.09	170.91	1401.01	0.715
2022-23*	1108.11	1320.18	203.55	1547.80	0.716
2023-24	1203.36	1408.45	225.83	1654.54	0.727
2024-25	1234.19	1461.85	255.01	1739.06	0.710

**For the years 2022-23 onwards, total CO2 emissions and total net electricity generation figures are are adjusted for cross-border electricity transfers and are inclusive of electricity injected into the grid by grid connected captive power plants*

***(Source:** https://cea.nic.in/wp-content/uploads/baseline/2025/12/User_Guide_V_21.0.pdf)*

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सत्यमेव जयते

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