AVALON Consulting

AN AVALON PERSPECTIVE

Powering Bharat's Future:

UNLOCKING THE NEXT WAVE OF GROWTH ACROSS INDIA'S ELECTRICITY VALUE CHAIN

BHARAT ELECTRICITY SUMMIT 2026
POWERING A CLEAN FUTURE

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Under the patronage of
GOVERNMENT OF INDIA
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EEPCINDIA
ENGINEERING THE FUTURE

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ABBREVIATIONS

Abbreviation	Full form
FY	Financial Year
INR	Indian Rupee
CMIE	Centre for Monitoring Indian Economy
CAPEX	Capital expenditure
kWh	kilowatt-hour
GOI	Government of India
NDC	Nationally Determined Contribution
MNRE	Ministry of New and Renewable Energy
EVs	Electric vehicles
TWh	terawatt-hour
V2G	Vehicle-to-Grid
GW	gigawatt
AI	Artificial Intelligence
EU	European Union
CBAM	Carbon Border Adjustment Mechanism
OPEX	Operating expenditure
MSMEs	Micro, Small and Medium Enterprises
PSP	Pumped Storage Project / Pumped Storage Plant(s) (usage varies)
SHANTI Bill	Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India
NPCIL	Nuclear Power Corporation of India Limited
SMRs	Small Modular Reactors
PIB	Press Information Bureau
CEA	Central Electricity Authority
kms.	kilometres
Hz	hertz
GVA	Gigavolt- ampere
HVDC	High Voltage Direct Current
AC	Alternating Current
FACTS	Flexible AC Transmission Systems
BHEL	Bharat Heavy Electricals Limited
AT&C	Aggregate Technical & Commercial (losses)
ACS–ARR	Average Cost of Supply – Average Revenue Realised
ADMS	Advanced Distribution Management System
DERMS	Distributed Energy Resources Management System
BESS	Battery Energy Storage System

ABBREVIATIONS

Abbreviation	Full form
CAGR	Compound Annual Growth Rate
RDSS	Revamped Distribution Sector Scheme
GFM	Grid-forming
MW	megawatt
IT	Information Technology
OT	Operational Technology
CERT-In	Indian Computer Emergency Response Team
CSIRT-Power	Computer Security Incident Response Team – Power (sector)
SOC	Security Operations Centre
OT-SOCs	Operational Technology Security Operations Centres
US	United States
FERC	Federal Energy Regulatory Commission
UHV	Ultra High Voltage
DC	Direct Current
EIB	European Investment Bank
EUR	Euro
AMI	Advanced Metering Infrastructure
EMS	Energy Management System
DERs	Distributed Energy Resources
VPPs	Virtual Power Plants
C&I	Commercial and Industrial
KPIs	Key Performance Indicators
NERC-CIP	North American Electric Reliability Corporation – Critical Infrastructure Protection
MMT	million metric tonnes
ALMM	Approved List of Models and Manufacturers
PLI	Production Linked Incentive
ISA	International Solar Alliance
COP21	21st Conference of the Parties (UNFCCC)
OSOWOG	One Sun One World One Grid
COP26	26th Conference of the Parties (UNFCCC)
GWh	gigawatt-hour
SEZs	Special Economic Zones
GH	Green hydrogen
EOUs	Export Oriented Units
SCADA/EMS	Supervisory Control and Data Acquisition / Energy Management System

ABBREVIATIONS

Abbreviation	Full form
ABB	ABB Ltd. (company name; originally Asea Brown Boveri)
HCLTech	HCL Technologies (brand: HCLTech)
T&D	Transmission and Distribution
VSC	Voltage Source Converter
LCC	Line Commutated Converter
OEMs	Original Equipment Manufacturers
kV	kilovolt
CII	Confederation of Indian Industry
SMNP	Smart Meter National Programme
MDMS	Meter Data Management System
PPP	Public-private partnership
InvIT	Infrastructure Investment Trust
PAT	Profit After Tax
LPS	Late Payment Surcharge
EMIs	Equated Monthly Instalments
CCTS	Carbon Credit Trading Scheme
BEE	Bureau of Energy Efficiency
VGF	Viability Gap Funding
PSDF	Power System Development Fund
IEA	International Energy Agency
ISTS	Inter-State Transmission System
TERI	The Energy and Resources Institute
RE	Renewable Energy
REZ	Renewable Energy Zone
CEEW-AEEE	Council on Energy, Environment and Water – Alliance for an Energy Efficient Economy
$MtCO_2$	million tonnes of carbon dioxide
bcm	billion cubic metres
IoT	Internet of Things
PG-AMRIT	POWERGRID Asset Management through Artificial Intelligence in Transmission
PALMS	POWERGRID Asset Lifecycle Management
IIT	Indian Institute of Technology
ToD	Time of Day
P2P	Peer-to-peer
NOCs	No Objection Certificates
PPA	Power Purchase Agreement

ABBREVIATIONS

Abbreviation	Full form
PM	Prime Minister
CERC	Central Electricity Regulatory Commission
MBED	Market-Based Economic Dispatch
RPO	Renewable Purchase Obligation
PRS	PRS Legislative Research (commonly “PRS India”)
DBT	Direct Benefit Transfer
LPG	Liquefied Petroleum Gas
NA	Not applicable / Not available
R&D	Research and Development

ACKNOWLEDGEMENT

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EXECUTIVE SUMMARY

India's electricity sector is entering a defining decade that will shape the country's economic, industrial, and developmental trajectory toward Viksit Bharat 2047. Electricity is no longer a passive infrastructure service; it has emerged as the central platform enabling industrial competitiveness, clean mobility, digital infrastructure, and inclusive growth. With non-fossil fuel sources already accounting for more than half of installed capacity (achieved well ahead of national targets), India has reached a structural inflection point in its energy transition.

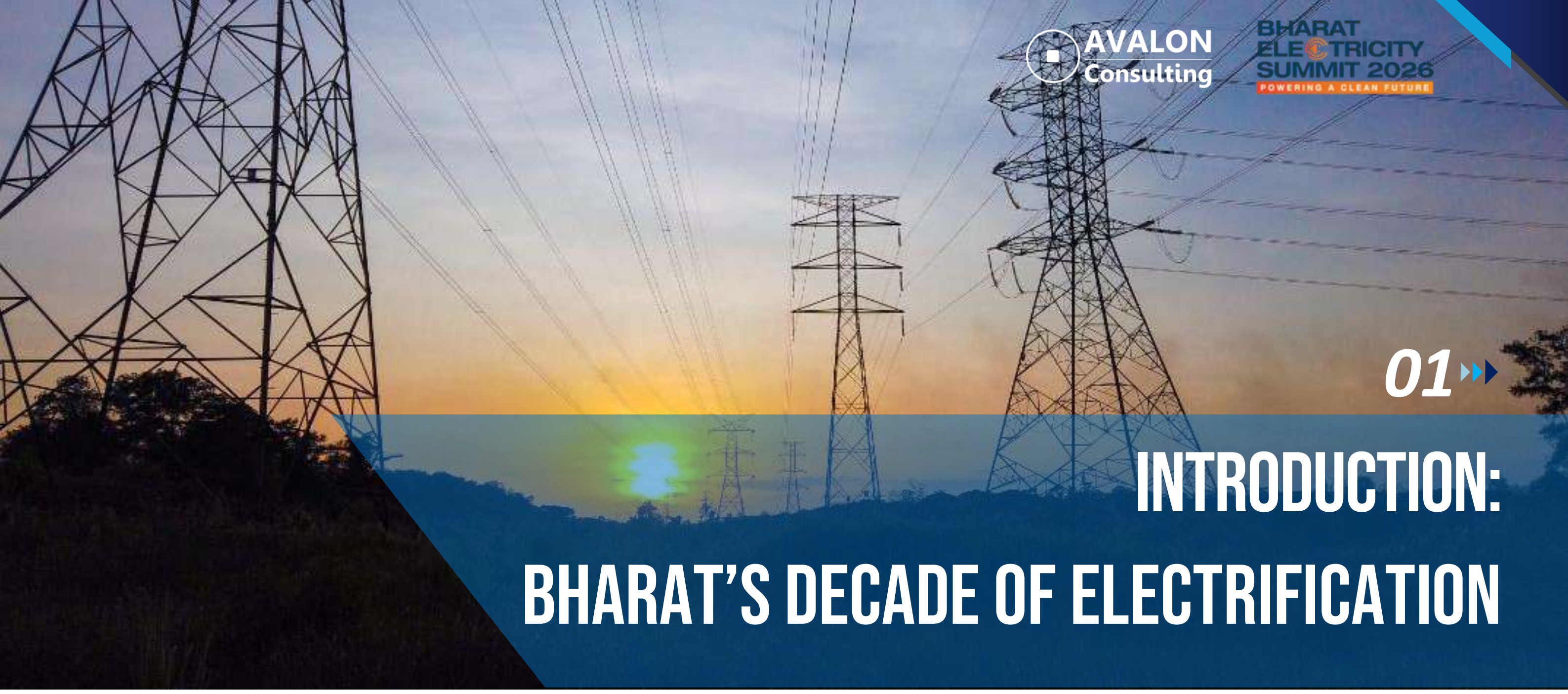
The coming phase of transformation will be driven by simultaneous, system-wide shifts across the electricity value chain. Electricity demand is set to accelerate sharply as electric mobility scales, data centres expand, industries electrify, and residential consumption rises. Meeting this demand reliably and affordably will require the power system to evolve from a centralized, one-way network into a flexible, intelligent, and digitally enabled grid. Investments in key areas will be critical to maintaining system stability while integrating large volumes of clean and variable power.

Beyond domestic transformation, India is uniquely positioned to convert its rising electricity demand into a source of global energy leadership. Scaling renewable manufacturing, green hydrogen ecosystems, offshore wind, and cross-border electricity and molecule trade can transform India from a large clean-energy consumer into a competitive exporter of green electrons, fuels, and equipment. Realizing this opportunity will depend on coordinated execution across financing innovation, supply-chain localization, workforce development, and regulatory modernization.

The central policy and industry challenge of the next decade is no longer capacity addition alone, but the simultaneous optimization of reliability, affordability, and sustainability. This requires restoring Distribution Company (DISCOM) financial health, reforming tariff structures and market design, enabling efficient national power markets, and ensuring that digitalization and flexibility are treated as core system assets rather than optional upgrades. Organizations that succeed will be those that view electricity as a strategic economic platform rather than a standalone infrastructure sector.

This white paper sets out 10 strategic imperatives to guide India's electricity sector through this transition. These include building a future-ready grid through expanded renewable backbone transmission, grid-scale flexibility, and cybersecurity; strengthening market design and bankability by restoring discom financial health, reducing cross-subsidies, and enabling efficient power markets; and capturing Viksit Bharat opportunities by aligning demand growth with industrial policy, scaling domestic manufacturing across clean energy value chains, and ensuring a just, inclusive energy transition. Together, these priorities will translate structural momentum into sustained, system-wide transformation.

Together, they provide a coherent roadmap to translate India's structural momentum into sustained, system-wide transformation over the coming decade.



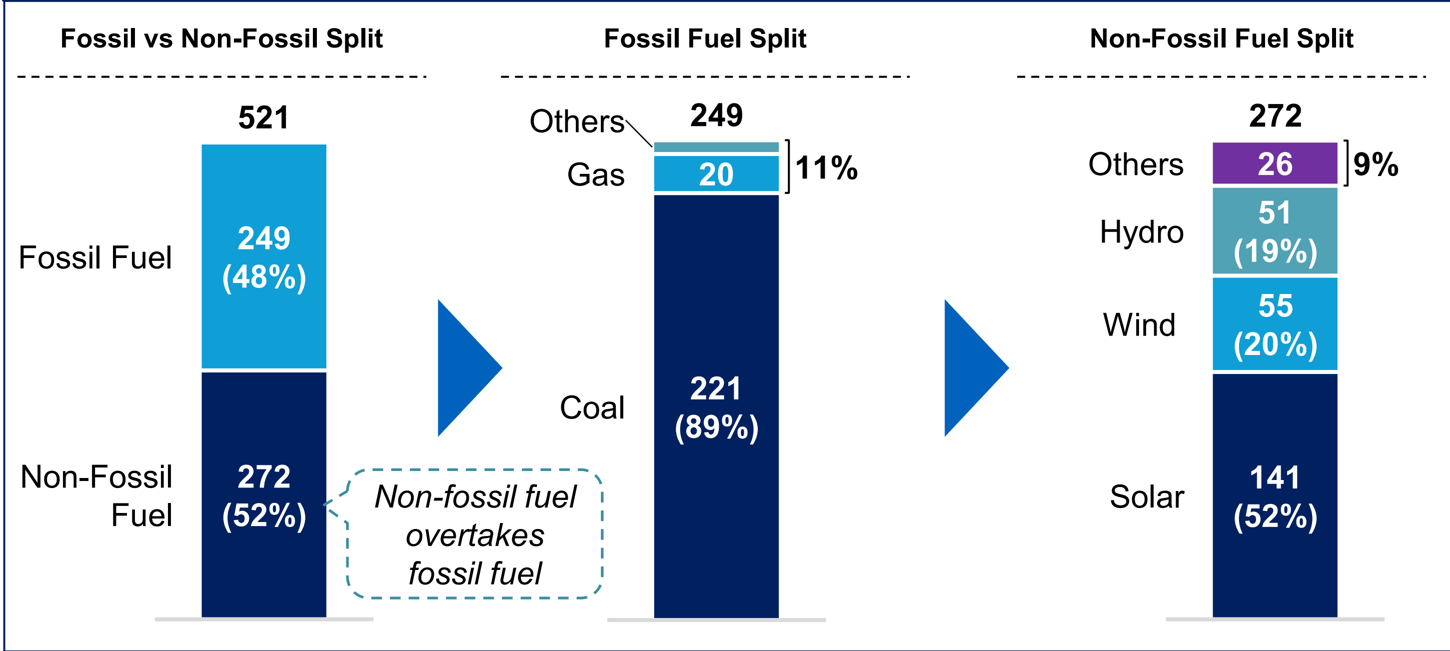
01

INTRODUCTION: BHARAT'S DECADE OF ELECTRIFICATION

1.1 Electricity as the backbone of Viksit Bharat 2047

India stands at a defining moment in its energy history. The vision of Viksit Bharat rests fundamentally on the transformation of the electricity sector, which must evolve from serving 1.4 billion people today to powering a **$30 trillion economy** supporting 1.5 billion citizens by 2047. This transformation demands nothing less than a complete reimagining of energy infrastructure at a scale unprecedented in human history. (EY)

Fig 1: Total Installed Capacity in India, in GW, till 31 January 2026



Source: Ministry of Power

This expansion transcends mere capacity addition. It represents a fundamental reconfiguration of how India produces, transmits, distributes, and consumes electricity. The **Draft National Electricity Policy 2026** codifies that per capita electricity consumption must reach 2,000 kWh by 2030 and exceed 4,000 kWh by 2047, up from the current baseline of 1,460kWh in 2025. These targets align India's energy trajectory with its climate commitments, i.e., 45% reduction in emissions intensity by 2030 relative to 2005 levels and net-zero emissions by 2070. (Ministry of Power, GOI)

1.2 India’s power sector at a positive structural inflection

India's power sector has crossed a historic inflection point in 2025, achieving 51.5% non-fossil fuel capacity five years ahead of the 2030 NDC target, a milestone that redefines the sector's trajectory. India’s power sector is now at a positive structural inflection driven by three levers of scale, digitization, and clean energy economics. (MNRE)

SCALE

- It is the ability of India’s power system to keep up with rapid economic growth and electrification
- India must sustain 60–70 GW of annual additions to match future demand. India is set to achieve the target but requires flawless execution across regulatory, financial, and operational domains

CLEAN ENERGY ECONOMICS

- Clean energy economics reflects India’s ability to turn renewables into the foundation of long-term energy growth
- The next phase depends on financial and policy execution. Reforms around tariffs, payment security, carbon markets, and financing mechanisms will determine the future of clean energy

DIGITIZATION

- Digitisation is India’s shift from manual grid operations to a smart, data-driven infrastructure
- Till 2030, execution will matter most. Decisions on interoperability, cybersecurity, and scaling digital grid systems will determine whether distribution networks become intelligent and efficient

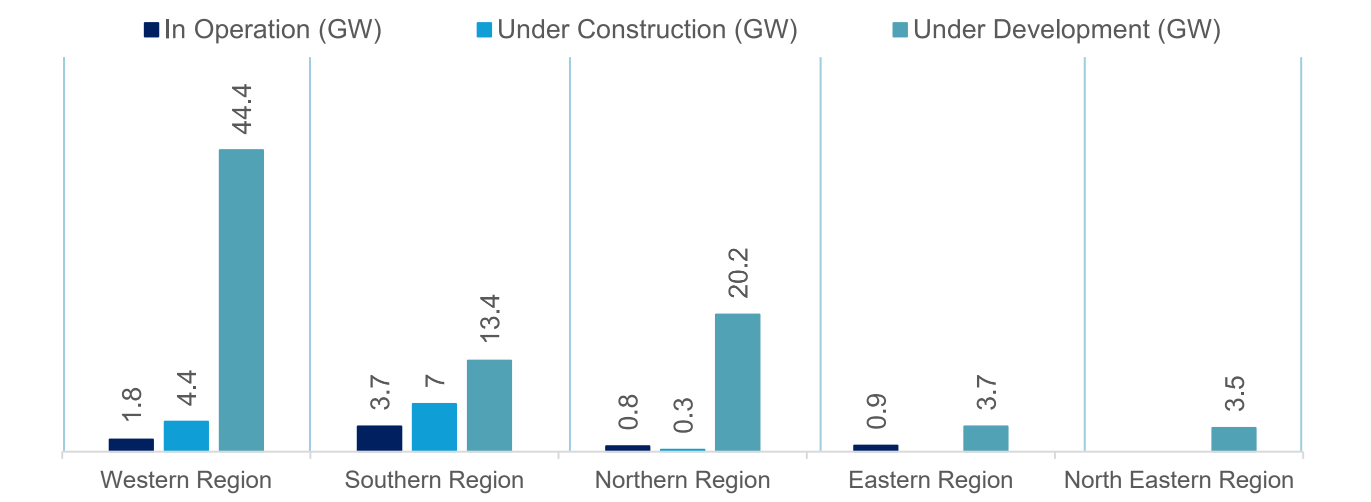
1.3 Key structural shifts

India’s power system is undergoing a structural pivot from thermal-centric to renewable-dominant, reshaping how the country meets fast-rising demand without locking into a high-carbon future. Non-fossil capacity has already crossed half of the installed base, and India is now targeting 500 GW of non-fossil capacity by 2030 alongside an emerging 100 GW nuclear ambition by 2047, positioning solar, wind, hydro, and nuclear as the backbone of firm, clean power. (MNRE)

At the same time, the architecture of the grid is shifting from a one-way, centralized system to a distributed network that integrates large utility-scale plants with distributed resources such as rooftop solar, behind-the-meter storage, and EV charging. Power will increasingly flow in multiple directions as households, MSMEs, and campuses both consume and produce electricity, making distribution networks as strategically important as generation capacity.

Pumped storage plants (PSP) are a hydro based “water battery” that shifts excess renewable power to peaks. India currently has about 7.2 GW operating, with another 11.6 GW of PSP under construction. Projects totalling roughly 9.6 GW are concurred, while nearly 75 GW is under survey and investigation. This pipeline reflects an assessed national PSP potential of around 267 GW across on and off stream sites. Looking ahead, installed PSP capacity is expected to reach about 87 GW by 2033–34. The roadmap then envisages crossing 100 GW by 2035–36, averaging 9 GW of new capacity annually. Planned additions align with projected storage needs of 62 GW by 2029–30 and 161 GW by 2034–35.

Fig 2: Region wise Pumped Storage Plants (PSP) Distribution in India (2026)



Source: Central Electricity Authority

The SHANTI Act, 2025 replaces India's legacy nuclear laws and marks the most significant reform of the sector since independence. It opens nuclear power to private and foreign participation, ending NPCIL's monopoly while keeping sensitive fuel-cycle activities under government control. The policy supports India's target of scaling nuclear capacity from 8.8 GW today to 100 GW by 2047, requiring ₹15–20 lakh crore of investment and a diversified reactor mix including SMRs. Liability reforms remove key barriers for global technology providers, enabling long-pending international partnerships. The Act also grants statutory independence to the regulator, strengthening safety oversight and improving investor confidence (PIB)

Clean energy economics are increasingly tilting decisively in favor of renewables and electrification in India, driven by sustained cost declines and scale advantages. Utility-scale solar and wind are now consistently the lowest-cost sources of new power, with tariffs well below new coal-based generation and insulated from fuel price volatility and import risks. When paired with storage—particularly pumped storage plants and, selectively, batteries—the effective cost of firm renewable power continues to fall, narrowing the gap with conventional baseload. As capital costs decline, financing deepens, and domestic manufacturing scales up, clean energy is no longer a climate-led choice but an economically rational one, reshaping generation planning, capacity addition decisions, and long-term power procurement strategies. At the system level, clean energy economics are also redefining how value is created across the grid. The shift from fuel-heavy operating costs to capex-heavy assets reduces long-term marginal costs while increasing the importance of utilization, flexibility, and data-driven optimization.

As electricity becomes the primary energy carrier for industry, mobility, and buildings, the competitiveness of India's broader economy will increasingly depend on access to affordable, firm, and predictable clean power—making clean energy not just cheaper electricity, but a foundational input to industrial productivity, energy security, and long-term growth.

Over the next 5–10 years, the winners across the power value chain will be those that treat data and digital intelligence as core grid infrastructure, not as add-ons. (CEA - PSP)

1.4 Growth drivers

The three areas of growth which will propel India's electricity consumption in the next decade will be:

Digital Infrastructure: Powering the Next Wave of Electrification	Industrial Decarbonization: Electrifying Hard-to-Abate Sectors	Rising Incomes: Fueling Consumption
Digital infrastructure is rapidly becoming foundational to India's electrified economy, enabling efficient energy use, smart consumption, and new value-added digital services	Industry accounts for a large share of energy demand in India. Electrification is key to decarbonising heavy sectors such as steel, cement, chemicals, and manufacturing	Rising incomes across India's population translate into greater demand for electricity-intensive goods and services—supporting overall electrification growth

India's upcoming decade of electrification will be strongly driven by the rapid expansion of digital infrastructure. The growth of data centres, cloud computing, AI workloads, 5G networks, and edge computing is creating a structurally higher and more stable demand for electricity. At the same time, grid digitalization through smart meters, automation, and real-time monitoring is improving reliability and enabling higher renewable integration.

A second major driver is industrial decarbonization, as India's manufacturing and heavy industries shift away from fossil fuels toward electricity-based processes. Sectors such as steel, cement, chemicals, refineries, and engineering goods are increasingly electrifying heating, mechanical drives, and auxiliary systems, supported by cleaner power from renewables. Emerging pathways such as green hydrogen further increase electricity demand upstream, even when electricity is not the final energy carrier. This transition is reinforced by global supply-chain pressures, carbon competitiveness, and policy support, making electrification central to India's industrial growth and export ambitions.

Finally, rising incomes and urbanization are expanding electricity demand from households and services. Higher disposable incomes are driving greater adoption of appliances and digital devices, while urban growth is increasing power use in commercial buildings, retail, healthcare, and entertainment. As per-capita electricity consumption rises from a relatively low base, this consumption-led demand becomes a durable growth engine for the power sector.

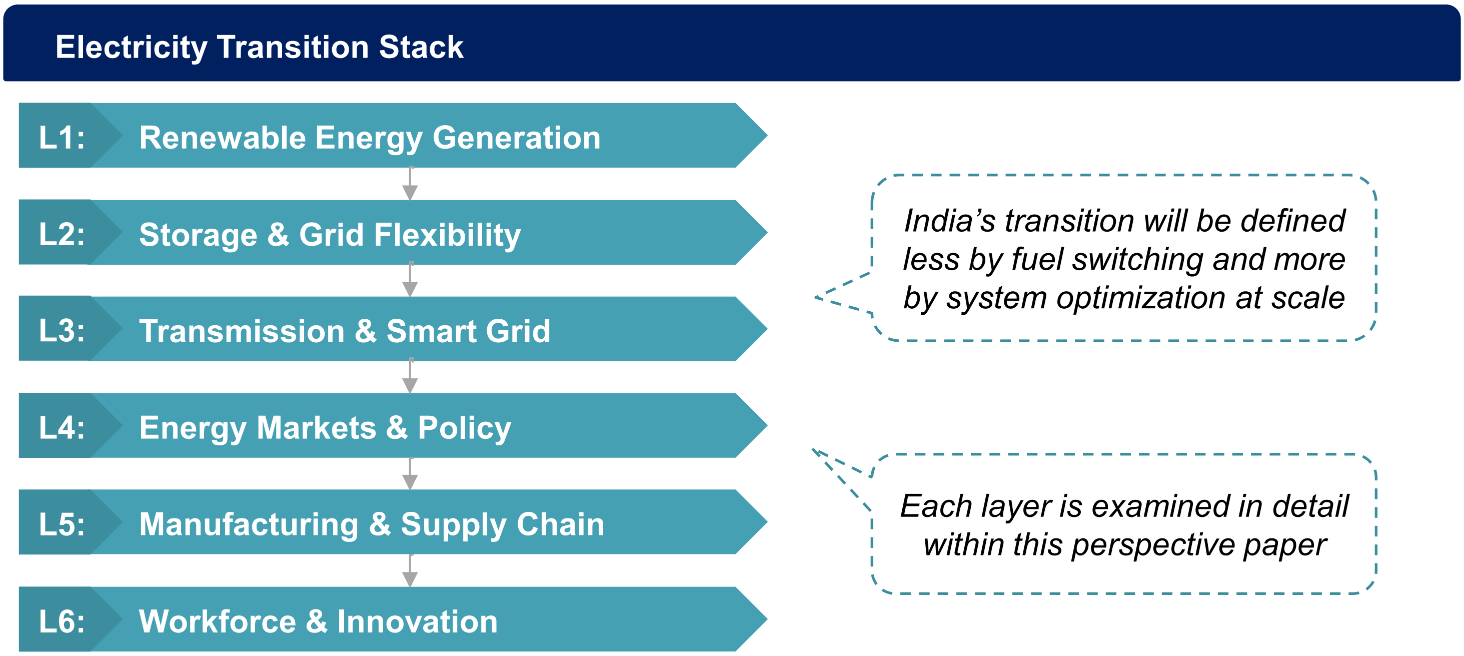
1.5 From energy trade-offs to energy optimization

India's power sector now faces an interesting dilemma, i.e., how to deliver round-the-clock, high-quality power to 1.4 billion people while keeping tariffs affordable and emissions on a net-zero-by-2070 pathway. Today, India still loses about one-sixth of the power it puts into the grid before it reaches paying customers, DISCOMs carry revenue gaps of over INR 1 per kWh and tens of thousands of crores in unpaid dues, yet non-fossil sources already constitute just over 50% of installed capacity and coal generation has begun to decline. The system must simultaneously fund trillions of new investments in renewables, storage, nuclear, and grid modernization, lower industrial and household tariffs to support growth and inclusion and cut technical/commercial losses to global best-practice levels, all while new loads from EVs, data centres, and cooling push demand to more than 4,000 TWh by 2035. The choices taken by industry and policy makers can solve this trilemma of reliability, sustainability, and affordability in the next decade that will determine whether the objective of a Viksit Bharat 2047 can be realized.

1.6 Energy Transition Management

India's energy transition will be defined less by rapid displacement of existing fuels and more by managed coexistence of new and legacy energy systems. Given the pace of economic growth, urbanization, and electrification, absolute demand for energy will continue to rise, implying that renewable capacity additions will largely meet incremental demand rather than replace existing thermal capacity. Reuters

As a result, no sharp reduction in coal or other non-renewables is required in the near term, except through end-of-life phase-out of inefficient assets. Transition management will therefore focus on improving efficiency, reducing emissions intensity, integrating renewables into the grid, and ensuring reliability—while avoiding energy shortages or cost shocks. Coal's role gradually shifts from baseload expansion to system balancing and energy security, with selective retirements aligned to asset age, efficiency, and regional grid stability. PIB



1.7 India-Specific Case Studies

Khavda Hybrid Park

Adani's Khavda Renewable Energy Park in Kutch, Gujarat is emerging as one of the world's largest hybrid RE sites, co-locating solar, wind, and storage across ~538 sq km. It exemplifies India's shift from single-technology projects to integrated, grid-supporting power parks that stress-test transmission and system-balancing capabilities at scale.

RDSS Smart Metering Rollouts

Under the Revamped Distribution Sector Scheme, over 250 lakh smart meters have been sanctioned and rollouts are under way across states like UP, Bihar, and Rajasthan, transforming real-time load visibility and billing efficiency for DISCOMs. These deployments directly validate the white paper's argument that making distribution "digital-first" is the fastest near-term affordability lever.

DRE Livelihood Outcomes

Distributed Renewable Energy solutions — from solar pumps in agri belts to solar-powered cold chains for small enterprises — have demonstrably improved productivity and incomes for MSMEs and farming households in states like Uttar Pradesh and Odisha. These outcomes ground the paper's inclusivity thesis, showing that energy access is a direct input to rural economic mobility, not merely a welfare measure.

02

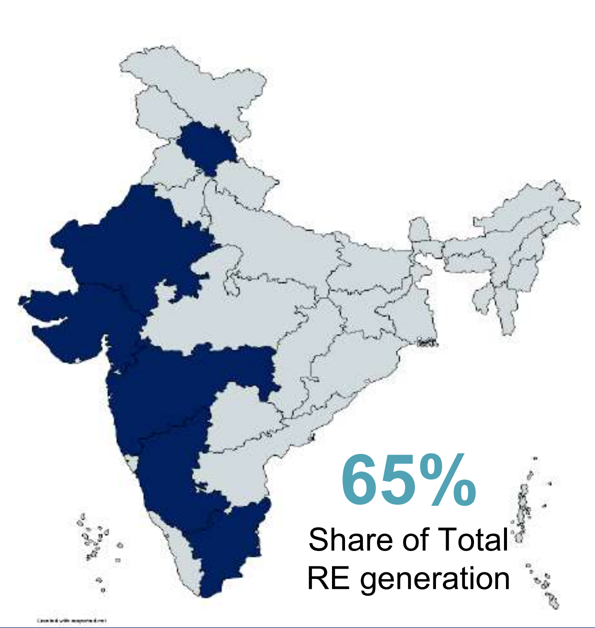
POWERING AN INTERCONNECTED WORLD

India's electricity grid stands at a decisive inflection point. The nation operates the world's largest synchronous grid spanning over 500,000 circuit kms., yet the architecture built to deliver coal-fired baseload power must now accommodate a fundamentally different energy system - one where 500 GW of variable renewables, distributed storage, electric vehicles, and data centres define operational reality. This section examines how India is accelerating grid modernization to transform transmission networks, distribution systems, and control infrastructure into a flexible, resilient platform capable of integrating renewables at unprecedented scale while maintaining the reliability that 1.4 billion people depend upon. EQ Magazine (ministry of power)

2.1 Inter-regional grid flows for renewable balancing

As of January 2026, India's inter-regional transfer capacity stands at 120 GW, having grown 230% since 2014. This expansion has operationalized the "One Nation-One Grid-One Frequency" vision, enabling seamless power exchange across five regional grids while maintaining a 50 Hz system frequency that ensures stability. CEA's National Electricity Plan (Transmission) envisages ~1.91 lakh ckm of new 220 kV+ lines, 1,270 GVA of transformation capacity (FY2023-32) and 33 GW of HVDC bi-poles. Inter regional capacity rises from ~119-120 GW (2024) to 168 GW by 2032. Total capex deployed will be INR 9.15 lakh crore through 2032.

Fig 3: Top Renewable Energy Generation States in India



Source: MNRE, Government of India

India's renewable energy resources are concentrated in distinct geographical zones. Solar in Rajasthan, Gujarat, and Karnataka, wind along coastal corridors, and hydro in the Himalayan states while demand centre cluster in Maharashtra, Tamil Nadu, Delhi-NCR, and industrial belts across the north and east. This spatial mismatch necessitates a transmission backbone capable of moving gigawatts of power across thousands of kilometres with minimal losses and maximum flexibility. Inter-regional transmission capacity has emerged as the critical enabler of India's renewable transition, allowing surplus solar generation in Rajasthan during midday to power industrial loads in Maharashtra, or hydropower from Himachal Pradesh to balance evening demand in Delhi.(Central Electricity Authority, Ministry of Power, PFC)

2.2 HVDC expansion & Flexible AC Transmission Systems (FACTS)

HVDC is becoming the backbone of India's long-distance renewable evacuation strategy, enabling multi-GW power transfer from resource-rich zones like Khavda to load centers with far lower losses and far greater controllability than conventional AC lines. Aggregate HVDC capacity is about 33.5 GW today and is expected to almost double to roughly 66.8 GW by FY2032, supported by nine new HVDC corridors and total transmission investments of around INR 9.15 - 10 lakh crores. Flagship projects such as the Khavda–Nagpur link, executed by a Hitachi Energy-BHEL consortium, illustrate India's pivot to ultra-high-voltage, with up to 80% of equipment now manufactured domestically under "Make in India". (Central Electricity Authority, BHEL Website)

In parallel, India's deployment of FACTS remains modest relative to the scale of its grid, but strategic applications are expanding. Gujarat Energy Transmission Corporation has installed next-generation firewalls and FACTS devices between remote control centres and the State Load Dispatch Centre to enhance both cybersecurity and dynamic voltage support. As renewable penetration rises and synchronous inertia from thermal generators declines, FACTS will become indispensable for maintaining voltage stability during faults, managing sub-synchronous resonance, and providing fast-frequency response.

2.3 Microgrids and distribution automation

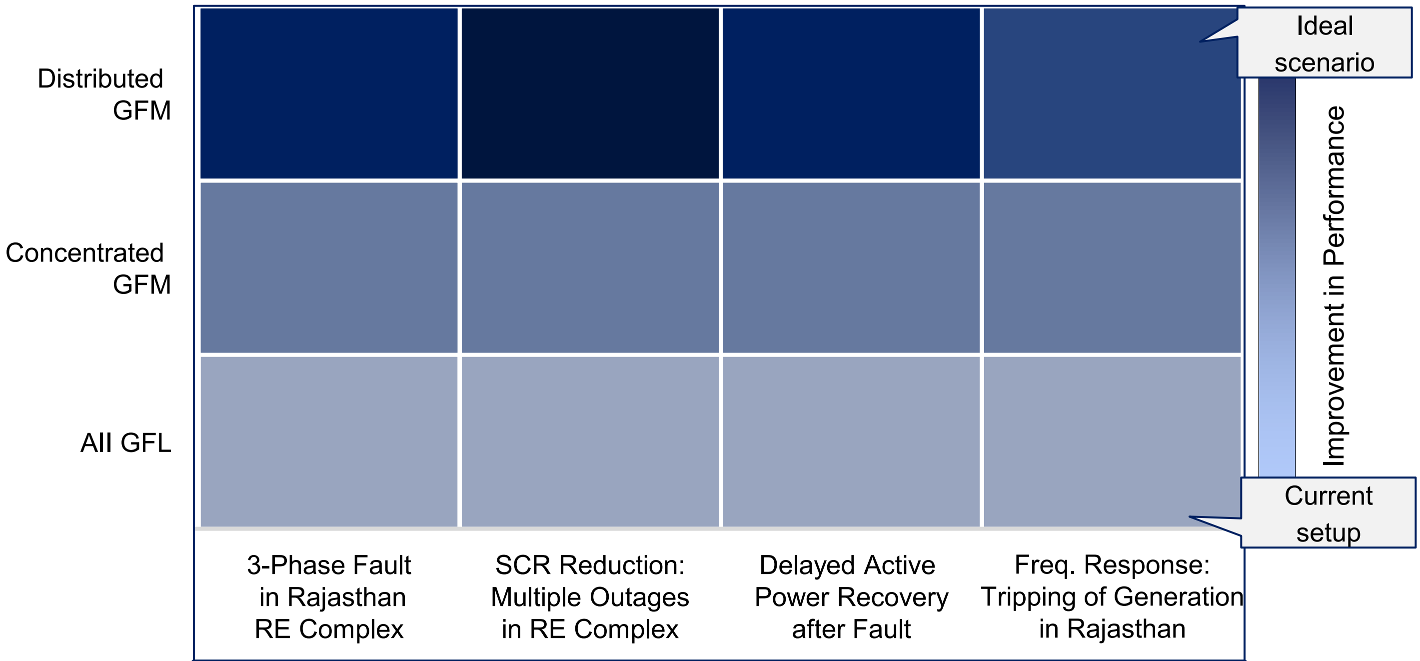
By 2030, India's distribution grid will be defined as much by software as by copper. Under the Revamped Distribution Sector Scheme, the government plans to replace 25 crore conventional meters with smart meters by FY2028, targeting AT&C losses of 12–15% and a zero ACS-ARR gap. This rollout approved for nearly 20 crore prepaid meters, creates a INR 1.83 lakh crore advanced metering and grid-analytics market and will give DISCOMs real-time visibility of loads, outages, and losses. ADMS and DERMS platforms will increasingly automate fault detection, isolation, and service restoration, while enabling granular time-of-day tariffs and demand response to manage EVs, rooftop solar, and emerging BESS fleets. Microgrids will shift from being a stop-gap for unelectrified villages to a strategic tool for reliability and productive use in weak-grid rural and peri-urban pockets, an India market projected to grow at around 8% CAGR to over 36,608 crore by FY2031. For regulators and DISCOM leaders, the next five years are about turning today's pilots into standardized, interoperable digital distribution platforms. (RDSS Scheme (Genus Power), Economic Times - Avener Capital, TechSci Research Report)

2.4 Grid-forming inverters and hybrid power parks

Grid-forming (GFM) inverters are emerging as the cornerstone of India's future grid because they turn inverter-dominated renewable plants from "grid takers" into active stabilizers. Grid-India's 2026 discussion paper shows that, compared with today's grid-following controls, GFM inverters significantly improve voltage stability, provide fast reactive power during faults, slow the rate of change of frequency near disturbances, and better damp low-frequency oscillations, especially in weak-grid, low-short-circuit-ratio conditions.

Building on this, India is likely to make GFM capability mandatory for all new BESS projects above 50 MW in weak or remote networks, and progressively for large hybrid parks, as the system moves toward 500 GW of non-fossil capacity. Hybrid power parks like the 30 GW Khavda complex, combining solar, wind and storage on shared HVDC corridors, will be designed around such GFM-enabled BESS, delivering near-firm, system-strengthening renewable clusters rather than standalone, variable plants. (Grid-India)

Fig 4: Heat map showing improvement in overall system performance with deployment of Grid Forming Technology (GFM)



Source: Grid Controller of India Limited

Roadmap: Grid forming (GFM) inverter adoption (2026–2030)

2026: "From paper to pilots"

- Grid India discussion paper proposes mandatory GFM for BESS ≥50 MW in weak/remote grids; invite comments; select 3–5 transmission connected pilots (hybrid park with BESS, black start demo, weak grid node)

2027: "Code the capability"

- Incorporate GFM capability & testing into CEA Grid Code and ISTS interconnection for qualifying BESS/hybrids; standardise compliance tests (fault ride through without PLL lock loss, RoCoF stabilisation)

2028–2029: "Scale with hybrids & RE parks"

- Require GFM enabled BESS for large RE parks and weak grid pooling stations (Rajasthan/Gujarat/South nodes referenced in Grid India studies); enable ancillary revenues (fast frequency, inertia, black start) in market design

2030: "Default in weak grids"

- Make GFM the default control mode for ≥50 MW storage at weak nodes; publish system stability KPIs (RoCoF containment, oscillation damping, fault recovery times) to show reliability gains

2.5 Cybersecurity in critical power infrastructure

Over the next decade, cybersecurity will become as fundamental to India's grid planning as n-1 reliability. The CEA's Draft Cyber Security in Power Sector Regulations, 2025 will convert today's guidelines into enforceable, auditable obligations for all generators, transmission licensees, DISCOMs, load despatch centres and key vendors, mandating rigorous controls for both IT and OT, frequent CERT-In–empanelled audits, strict remote-access policies, and time-bound closure of critical vulnerabilities. CSIRT-Power and six sectoral CERTs (for thermal, hydro, transmission, distribution, grid operation and renewables) will anchor a coordinated, sector-wide incident response regime, supported by model Cyber Crisis Management Plans and regular cyber-drills. GRID-India's 24×7 security operations centre is a preview of the future: AI-enabled OT-SOCs that baseline real-time grid behaviour, correlate cyber alerts with frequency and load conditions, and orchestrate automated response playbooks without compromising system stability. (Ministry of Power, Central Electricity Authority)

2.6 Case Insight: Global best practices – US, EU, China

Table 1: Case studies from mature global markets

Theme	USA	EU	China
Renewable interconnection & queue management	FERC Order 2023 replaces "first-come, first-served" serial studies with cluster studies, first-ready-first-served prioritization, firm study deadlines and penalties, and requires evaluation of alternative transmission technologies and co-located resources	EU Grids Package promotes forward-looking network planning for high renewables, harmonised connection rules, and outcome-based KPIs (shorter queues, lower curtailment, reduced congestion) for distribution and transmission grids	Centralised planning aligns large renewable bases with backbone UHV corridors, avoiding ad-hoc, project-wise evacuation and shortening effective interconnection timelines for priority projects
Long-distance transmission for RE corridors	Regional transmission organisations and independent system operators run competitive planning for multi-state lines, increasingly considering advanced conductors and grid-enhancing technologies to maximise transfer capacity on existing corridors	Cross-border "Projects of Common Interest" and EIB/EU blended finance de-risk strategic interconnectors, with a 1.2 trillion EUR grid investment need estimated to 2040, >60% in distribution	Nationwide UHV AC/DC backbone (45,000+ ckm) moves bulk wind/solar/hydro from west and north to coastal load centres, cutting thermal generation and supporting desert-based mega RE bases
Smart grids, digitalization, ADMS/DERMS	Advanced distribution utilities integrate ADMS, DERMS and AMI with granular locational pricing and demand response, enabling DERs and VPPs to provide ancillary services alongside traditional plants	Grids Package explicitly prioritises digitalisation (ADMS, EMS, cloud-based supervision) and demand-side flexibility, making IT/OT upgrades eligible for EU and EIB support and setting harmonised performance KPIs	System operators deploy wide-area monitoring, PMUs and digital twins to manage the world's largest synchronous grid and UHV network, enabling real-time stability management of multi-GW corridors

2.6 Case Insight: Global best practices – US, EU, China

Table 1: Case studies from mature global markets

Theme	USA	EU	China
Virtual power plants & flexibility markets	DOE and regulators support large-scale VPPs; aggregation of residential and C&I DERs already delivers tens of MW in markets like California and Texas, with a 30–60 GW national VPP potential (4–8% of peak demand)	Several member states enable aggregators to participate directly in balancing markets; EU emphasises standardized flexibility products and non-wires alternatives in planning	Pilots aggregate distributed solar, storage and flexible industrial loads to provide peak shaving and reserve, coordinated centrally with UHV backbone dispatch
Transmission planning & cost allocation	FERC Orders 2023 and related reforms push long-term, scenario-based transmission planning and more transparent, beneficiary-pays cost allocation across regions and states	EU-wide planning identifies priority corridors and interconnectors, with regulatory incentives for anticipatory investment and simplified permitting for strategic grid projects	Unified national transmission planning by State Grid / China Southern Power Grid aligns UHV expansion with 2030/2060 climate targets and regional development strategies
Cybersecurity & grid resilience	NERC-CIP standards mandate rigorous, auditable cyber controls for bulk power system assets, with enforced incident reporting and penalties for non-compliance	EU framework integrates cyber resilience into energy legislation and the Grids Package, emphasising secure-by-design digitalisation and cross-border incident coordination	Power utilities deploy integrated security operations across UHV and regional grids, increasingly using AI analytics for anomaly detection in OT networks

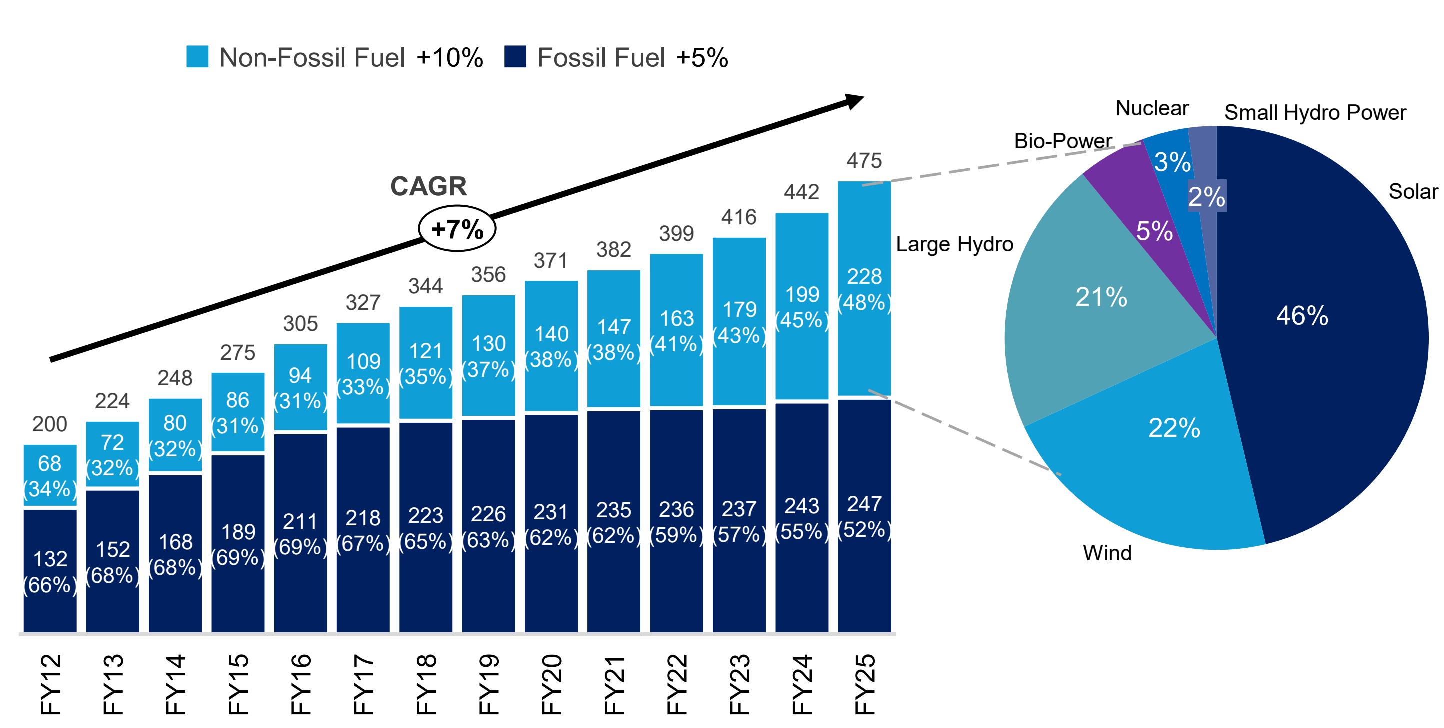
03

POWERING INDIA'S ENERGY LEADERSHIP

3.1 Diversification of renewables portfolio of India

India's renewable energy portfolio remains concentrated in solar, which accounts for 106 GW of the 228 GW installed base as of FY2025, creating operational vulnerabilities during monsoon cloud cover and evening hours. Achieving the 500 GW target by 2030 requires deliberate diversification. Wind repowering of outdated turbines offers immediate potential, while green hydrogen production targeting 5–8 MMT by 2030 will drive 125+ GW of dedicated renewable capacity. Battery storage scaling to 41–66 GW enables multi-hour load shifting, transforming solar surplus into evening peak supply. Hybrid projects co-locating solar and wind exploit complementary generation profiles to deliver flatter, more dispatchable output. Over the next five years, success will hinge on accelerating wind and nuclear additions, deploying storage at scale, and financing the large investment required to simultaneously meet 500 GW targets and enable industrial decarbonization, data centre growth, and EV charging demand. (Wright Research)

Fig 5: Installed Capacity (in GW) trend in India (FY12-25) and % share of the non-fossil fuel capacity as of FY25



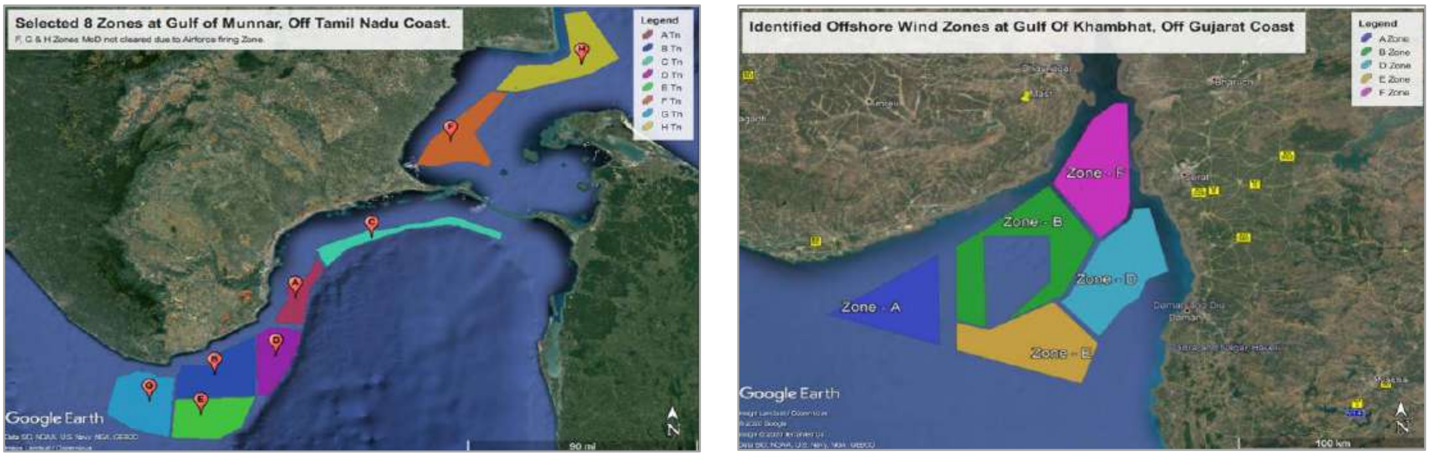
Source: Central Electricity Authority

3.2 Turning India’s energy demand into a global manufacturing advantage

India's solar manufacturing sector is undergoing a transformation as profound as its deployment surge. As of November 2025, the country's annual solar photovoltaic module production capacity reached approximately 144 GW under the Approved List of Models and Manufacturers (ALMM) List-I, nearly doubling from a year earlier. Cell manufacturing capacity enlisted under ALMM List-II grew to around 24 GW, with Production Linked Incentive (PLI) beneficiaries contributing 11 GW of module and 5 GW of cell capacity in 2025 alone. India is rapidly becoming the world's second-largest solar module manufacturer after China, with capacity on track to reach 150 GW by June 2026. (MNRE, MNRE Comms)

3.3 Offshore wind & round-the-clock renewable power opportunities

Fig 6: Demarcated offshore wind energy zones in Tamil Nadu and Gujarat coasts



Source: : Ministry of New and Renewable Energy

India's 7,600 kms coastline offers untapped potential that could redefine the nation's renewable energy architecture. The World Bank estimates 91 GW of bottom-fixed and 83 GW of floating offshore wind potential, with the most promising sites concentrated off the coasts of Gujarat and Tamil Nadu. Unlike onshore wind resources constrained by land availability, transmission corridors, and local opposition, offshore installations exploit higher and more consistent wind speeds, achieve capacity utilization factors exceeding 40% versus 25-30% for onshore turbines, and face minimal land acquisition challenges. Yet despite this potential, India's operational offshore wind capacity remains zero as of early 2026, positioning the sector at the same inflection point onshore wind occupied a decade ago. The Ministry of New and Renewable Energy has charted an aggressive deployment roadmap targeting 30 GW of offshore wind capacity by 2030, with 37 GW specifically planned for Gujarat and Tamil Nadu. (International Trade Administration (USA), CEEW Council)

3.4 India as a global clean-energy export hub – South-east Asia & Middle East focus

India is positioning itself as a global clean-energy export hub through the National Green Hydrogen Mission, supported by OSOWOG and the India–Middle East–Europe Economic Corridor (IMEC). The strategy combines exports of green electrons (renewable electricity) and green molecules (hydrogen, ammonia, methanol, and SAF). Cross-border electricity trade has already expanded from 1,400 MW in 2012 to ~4,100 MW in 2024, and is expected to reach ~7,000 MW by FY27. On the fuel side, early bilateral agreements with Japan, Singapore, and South Korea are creating long-term demand corridors, while cost competitiveness is improving rapidly with SECI's 2025 auction discovering green ammonia prices at ₹49.75/kg (~US$572/ton). RE Global

India is developing large-scale infrastructure to enable exports. Two undersea HVDC links from Gujarat to Saudi Arabia (2 GW, ~₹47,000 crore) and the UAE (2 GW, ~₹43,000 crore) are under feasibility, while IMEC aims to reduce logistics costs by up to 30% and transit time by 40%. Ports such as Kandla, Paradip, and Tuticorin have been designated Green Hydrogen Hubs, with bunkering and refuelling facilities planned by 2030. Kandla alone has received 13 global EOIs for a 7 MTPA green ammonia facility, while projects at Gopalpur exceed 1.1 MTPA.

India is also expanding into green methanol exports and SAF, targeting blending levels of 1% (2027), 2% (2028), and 5% (2030). (HVDC World). NITI Aayog's Methanol Economy programme aims to reduce India's oil import dependence and GHG emissions while leveraging coal, municipal solid waste, biomass, and green hydrogen. Blending 15% methanol (M15) in gasoline can reduce gasoline/crude imports by ~15% and cut particulate matter, NOx, and SOx emissions by ~20%, improving urban air quality. In parallel, 20% DME blending in LPG can save ~₹6,000 crore annually and reduce household LPG costs by ₹50–100 per cylinder. The programme is also expected to generate ~5 million jobs across methanol production, applications, and distribution.

On the policy and adoption side, the Bureau of Indian Standards has approved 20% DME blending in LPG, while the Ministry of Road Transport and Highways has notified M15, M85, and M100 fuel blends, with testing underway in collaboration with Indian Oil Corporation Limited, the Automotive Research Association of India, and the Society of Indian Automobile Manufacturers. Indian Railways, through RDSO, is evaluating 5–20% methanol blending in locomotives. Planned infrastructure includes five coal-based methanol plants, five DME plants, and a large natural gas–based methanol facility. Methanol-powered boats and cargo vessels are also being developed by Cochin Shipyard Limited for the Inland Waterways Authority of India.

On the technology and R&D front, Thermax has developed a 5 kW methanol-based reformer using direct methanol fuel cell technology, while Kirloskar Oil Engines has successfully converted generator sets to operate on 100% methanol and is scaling this in partnership with Dor Chemicals (Israel). Indigenous coal-to-methanol technologies are being developed by BHEL, Thermax, and IIT Delhi, with multiple demonstration plants under development. Biomass-to-methanol R&D is also underway through a Department of Biotechnology project involving IISc Bengaluru and Praj Industries. NITI Aayog

Momentum is accelerating in green and e-methanol, led by industry players. ACME Group is developing a ~200 ktpa green methanol project in Odisha, while Assam Petro-Chemicals Limited has partnered with the Deendayal Port Authority to set up an e-methanol plant at Kandla. NTPC Green Energy Limited has issued tenders for green methanol and ammonia under its Pudimadaka Green Hydrogen Hub and signed an MoU with ENEOS to explore marine fuel applications. Welspun New Energy, Oswal Energies Limited, and Toyo Engineering India are also advancing port-led green methanol, hydrogen, and ammonia projects, signaling the emergence of an integrated low-carbon methanol value chain in India.

India's sustainable aviation fuel (SAF) ecosystem is gaining momentum across refiners, technology providers, airlines, and OEMs. IndianOil became the first Indian company to receive ISCC-CORSIA certification for SAF production at its Panipat refinery, and has signed an MoU with Air India to supply SAF. On the technology side, Honeywell is working with TruAlt Bioenergy Limited to deploy its ethanol-to-jet (ETJ) process in India, targeting ~80,000 tonnes per annum of SAF, while separately partnering with NTPC Green Energy Limited to explore SAF pathways using CO_2 and green hydrogen.

Project development is also accelerating, with SAF One Energy Management Limited partnering Tata Projects Ltd. to build scalable SAF infrastructure, and GPS Renewables collaborating with SAF One to develop SAF plants using agricultural residues such as paddy straw. Global aerospace players are supporting ecosystem development, with Boeing partnering HPCL to advance SAF adoption, and Airbus setting up a CoE at Gati Shakti Vishwavidyalaya focused on sustainable aviation technologies, including MSW-to-SAF research. Airlines are beginning early adoption, with IndiGo, Vistara, and AIX Connect operating SAF-blended international, wide-body, and domestic flights, respectively—signaling a shift from pilot projects to early commercial deployment in India.

The scale-up pipeline is significant. The Central Electricity Authority estimates ~40 GW of power demand from green hydrogen and derivatives by 2032, with major projects including Adani's 16–22 GW development at Mundra and multi-MTPA plans by RIL, L&T, Greenko, ACME, and Avaada. If execution remains strong, India can evolve from a clean-energy consumer to a major global exporter — linking low-cost renewables with growing international demand. (Central Electricity Authority)

3.5 Lead global standards for clean energy such as International Solar Alliance

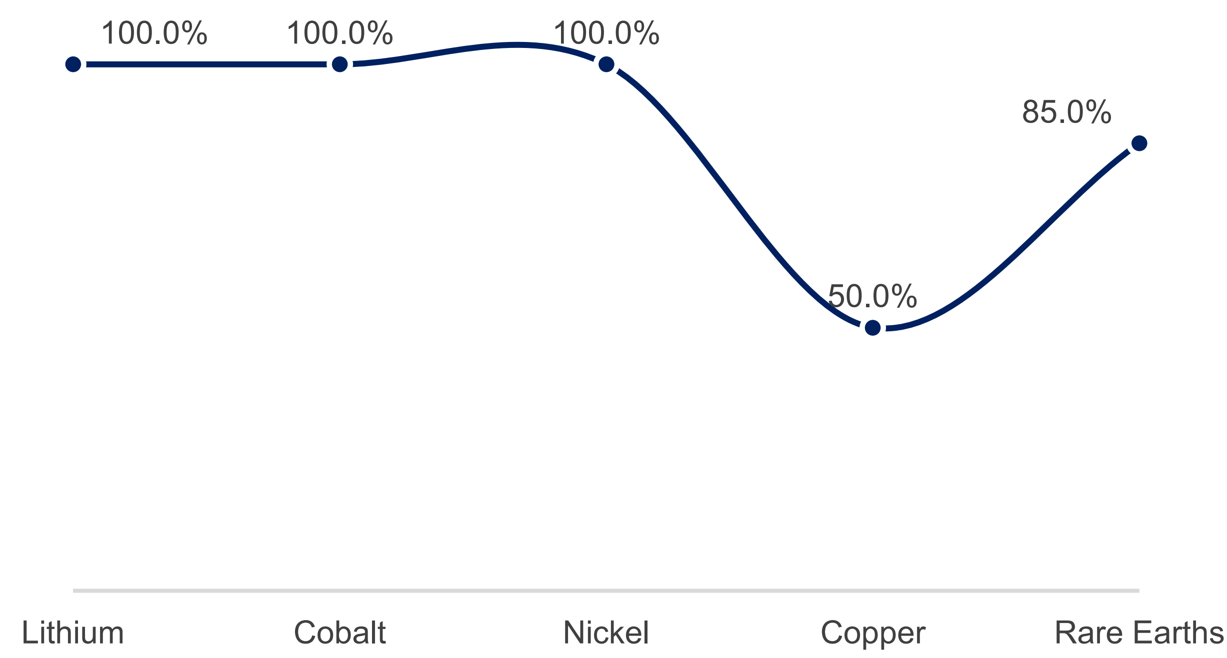
The International Solar Alliance (ISA), headquartered in Gurugram and launched at COP21 in 2015, now encompasses 125 member countries committed to mobilizing $1 trillion in solar investment by 2030, delivering energy access to 1 billion people, and installing 1,000 GW of solar capacity globally. India holds the ISA presidency and leads the 'Towards 1000' strategy. The alliance operates in 95+ countries, providing technical assistance, finance de-risking through the Global Solar Facility, and capacity building that has halved global solar pump costs. One Sun One World One Grid (OSOWOG), India-led and merged with the UK's Green Grids Initiative at COP26, targets connecting 140 countries with 2,600 GW of cross-border transmission capacity by 2050, enabling round-the-clock solar-powered electricity flows. Eighty-three ISA members endorse OSOWOG, with pilot interconnections underway in South Asia and the Middle East.

04

POWERING ELECTRIFICATION'S SUPPLY CHAIN EVOLUTION

4.1 Battery value chain: minerals → cell → pack → recycling

Fig 7: India's critical minerals import dependency



Source: Eninrac Consulting

India remains 100% import-dependent for lithium, cobalt, and nickel, the trinity of minerals underpinning lithium-ion batteries, with China controlling the refining bottleneck for all three. Annual battery demand will surge from 40 GWh today to 210 GWh by 2030. The PLI scheme for Advanced Chemistry Cells, approved in May 2021 with INR 18,100 crore outlay, targets 50 GWh of domestic cell manufacturing by 2030, yet only 1 GWh is operational as of 2025 despite 178 GWh of announced private capacity from Reliance, ACC, Ola, and others. The National Critical Minerals Mission is accelerating domestic exploration while Khanij Bidesh India has acquired lithium blocks in Argentina in 2024. But the Argentinian mines will take a decade to produce. Battery recycling emerges as the strategic wildcard. By 2050, domestic recycling could supply over 40% of India's lithium, nickel, and cobalt requirements, create 106,000 green jobs, and unlock a INR 75,500 crore market opportunity making circularity not an environmental nicety but an economic and security imperative. (Eninrac Consulting, Ministry for Heavy Industries, GOI, Ministry of Heavy Industries, GOI, RMI)

4.2 Grid-equipment manufacturing competitiveness

India's power transmission equipment market will double to INR 2 lakh crore by 2034, propelled by 500 GW renewable integration, Green Energy Corridors, and the addition of more than 1.95 lakh circuit kms of transmission lines in the last 10 years. BHEL commands 55% share in India's total installed capacity of utility power segment (excluding renewables) and the remaining is manufactured by L&T, GE Vernova, Siemens Energy, BGR Energy among others.

HVDC supply chains in India are bottlenecked because critical components for LCC and VSC systems are concentrated with just three global OEMs (GE, Hitachi Energy and Siemens) leading to long lead times and systemic execution risk. There are three possible solutions:

Standardize VSC ratings/ specs to enable platform manufacturing at scale

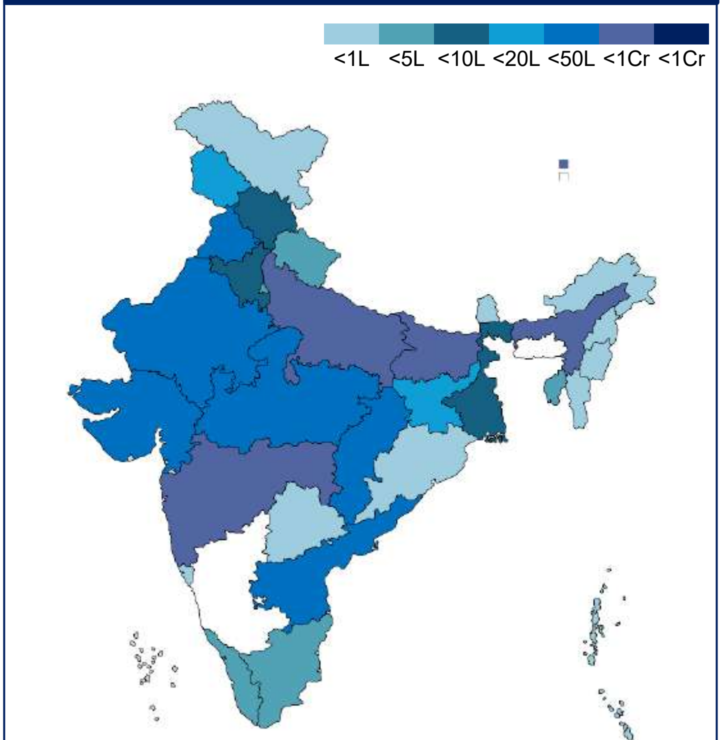
Relax land-border–linked procurement rules for firms with plants in India to broaden qualified supply

Allow targeted imports of 765 kV transformers/reactors for time-critical projects to avoid renewable evacuation delays from OEM capacity constraints

Standardization at 220 kV and 132 kV voltage levels remains fragmented across states, imposing inefficiencies and custom-design burdens that the Confederation of Indian Industry estimates add 10-15% to project costs. (IMARC Group, CII)

4.3 Localizing smart meters and grid automation components

Fig 8: State wise smart metering status in 2026



Source: National Smart Grid Mission, Ministry of Power

India has sanctioned 23 crore smart meters installation yet only 5.6 crore meters (24% of target) are installed as of 2026. This is forcing a rapid shift from import dependence to a largely domestic supply base, with RDSS (Revamped Distribution Sector Scheme) and the SMNP (Smart Meter National Programme) initiatives giving long-term demand visibility that justifies local manufacturing lines. The smart meter hardware is increasingly sourced from Indian plants as global firms either set up local factories or acquire local manufacturers (e.g. Kaynes Technology acquired Iskraemeco India, a specialist in smart meter solutions). This is creating a tiered ecosystem of meter manufacturers, communication module suppliers, and MDMS/software providers built around Indian conditions rather than importing "as-is" designs. (Ministry of Power, Kaynes Technology PR)

On the automation side, Power Grid Corporation has awarded a INR 490 crore SCADA/EMS contract to GE T&D India, to be engineered and supported from its Indian facilities. Hitachi Energy, Siemens, and ABB also operate Indian bases supplying transformers, protection, and automation systems for domestic and export markets. Utilities are deploying ADMS platforms that integrate SCADA, outage management, and DER management, with implementations led by global OEMs and Indian IT integrators such as HCLTech. Under RDSS and smart grid programmes, common specifications and interoperable architectures for AMI, head-end systems, and MDMS are intended to build a domestic vendor ecosystem and increase localisation. (IIFL Capital, Hitachi Energy PR, HCL Tech Case Study, CEA PR)

4.4 Green hydrogen ecosystem & electrolysers

India's green hydrogen supply chain is being built ground-up to avoid replicating the import dependence that marked the early solar era. Under the SIGHT scheme (₹17,490 crore outlay), 15 companies, including Reliance, Adani, L&T, and Ohmium, have been awarded 3,000 MW per annum of electrolyser manufacturing capacity, supported by ₹4,440 crore in dedicated incentives, with installed capacity projected to reach 15 GW by 2030. On the production side, 19 companies have been allocated 8.62 lakh tonnes per annum of green hydrogen capacity and 7.24 lakh tonnes per annum of green ammonia capacity, backed by ₹13,050 crore in production incentives. The Mission targets ₹8 lakh crore in total investment, 6 lakh+ jobs, and a ₹1 lakh crore annual reduction in fossil fuel imports by 2030, positioning electrolyser localisation as the linchpin of India's strategic energy independence. (PIB, Nov 2025, PIB, Jun 2023, PIB, Nov 2025, Invest India, Jan 2026, PIB, Nov 2025)

4.5 PLIs, SEZs, and logistics clustering opportunities

The Solar Module PLI scheme, with an outlay of INR 24,000 crore, has operationalized 18.5 GW of module capacity and 9.7 GW of cell capacity, while the Advanced Chemistry Cell battery PLI scheme, with an allocation of INR 18,100 crore, and the electrolyzer PLI scheme, with INR 4,440 crore in support, are driving domestic manufacturing scale-up in their respective segments. There is a lag in timely execution which needs to be worked upon.

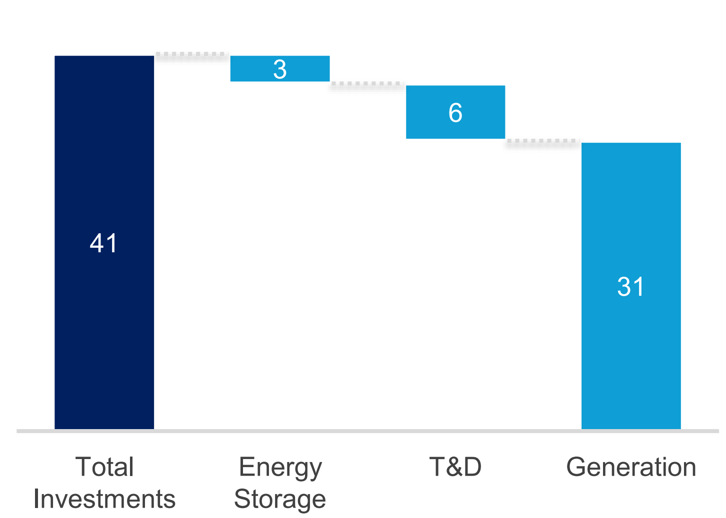
Special Economic Zones (SEZs) unlock strategic advantages. 213 operating SEZs collectively offer ~1,080 MW of onsite solar potential, with Gujarat, Andhra Pradesh, Maharashtra, Odisha, Tamil Nadu, Karnataka, Rajasthan and Telangana dominating 85% of capacity. Green hydrogen (GH) projects in SEZ/EOUs receive Approved List of Models and Manufacturers (ALMM) exemptions and duty benefits for renewable equipment through December 2030, while proposed multi-locational SEZ frameworks accommodate wind turbine spacing requirements for GH production.

Logistics clustering concentrates manufacturing in Gujarat, Karnataka, and Telangana enabling integrated supply chains that co-locate renewable generation, battery/electrolyzer production, and end-use industries while leveraging Gati Shakti infrastructure for collection and transport. (MNRE, EQ Mag Pro, ET Energy World, WRI India, ET Energy World (GH))

05

POWERING FINANCE AND INVESTMENT

Fig 9: India's INR 41 lakh crore power sector investment opportunity by 2032



Source: : Ministry of Power

India's power sector is expected to attract about INR 40.68 lakh crore of investment by 2032, with INR 31.32 lakh crore in electricity generation, INR 6.18 lakh crore in transmission and distribution, and INR 3.19 lakh crore in energy storage. This breakdown, outlined by the Union Power Minister at the Bharat Electricity Summit 2026 curtain-raiser, underscores how financing strategies must differ by segment: generation needs deepening of project finance, corporate capital, and green bonds; T&D requires predictable regulated returns and InvIT-driven asset recycling; while storage - still at a nascent cost curve - will rely on targeted instruments such as viability gap funding, concessional capital, and blended finance to reach scale. (Economic Times)

5.1 Bridging financing gaps: DISCOM risk mitigation, payment security

DISCOM balance sheets remain the core bankability bottleneck for India's power transition, with accumulated losses of INR 6.48 lakh crore, accumulated debt of INR 6.84 lakh crore, and an ACS-ARR gap of INR 0.45/kWh as of FY23. However, the trajectory is improving. AT&C losses at the national level reduced from 21.91% in FY21 to 15.04% in FY25, the ACS-ARR gap has narrowed from ₹0.78/kWh to ₹0.06/kWh, and distribution utilities recorded a positive PAT for the first time in years. The Electricity (Late Payment Surcharge and Related Matters) Rules, 2022 have been central to this shift, structuring legacy dues into EMIs and enabling power regulation for persistent non-payment of current dues. In May 2025, the Ministry of Power extended LPS coverage to intra-state transmission licensees, closing a gap that had left renewable evacuation networks exposed to payment delays. For investors and lenders, the risk stack now rests on three pillars:

- **Counterparty assessment (ACS-ARR trajectory, subsidy discipline)**
- **Payment security instruments (letters of credit, escrow, advance payments)**
- **Enforcement teeth (LPS-linked curtailment)**

(Ministry of Power, Ministry of Power PR, Ministry of Power PR)

5.2 Green bonds, blended finance, carbon markets, transition finance

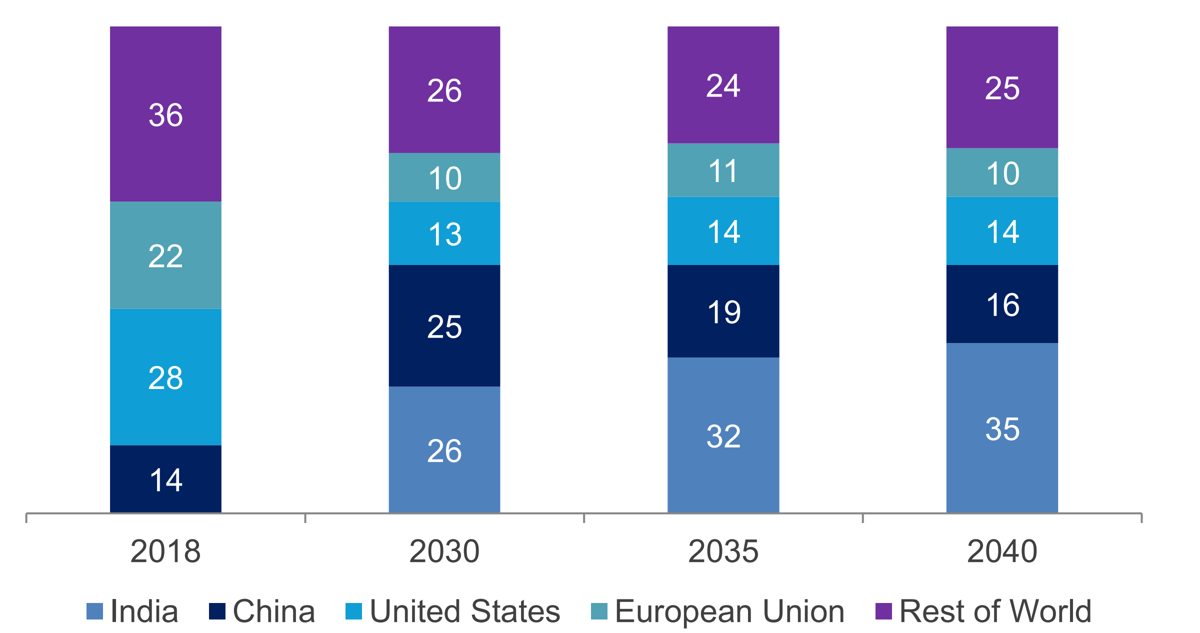
India is expanding green capital channels, including sovereign green bonds that total INR 72,697 crore cumulatively since FY23, with INR 15,000 crore issued in FY26 alone. Financing India's 2030 renewables ambition has been estimated at an average of INR 2.53 lakh crore annually during 2022–2029, highlighting the need to crowd in longer-tenor domestic capital beyond conventional bank lending. Blended finance is positioned as a catalytic tool to de-risk early-stage or higher-perceived-risk segments and unlock private capital at scale, particularly as public resources face competing priorities.

Carbon markets are also being institutionalised via India's Carbon Credit Trading Scheme (CCTS), with Grid-India as the Registry and the Bureau of Energy Efficiency as Administrator, operating through both Compliance and Offset mechanisms. CEEW notes that the CCTS offset mechanism creates a government-certified standard within India's voluntary carbon markets, distinct from independent standards (e.g., Verra, Gold Standard). (Ministry of Finance, Bloomberg NEF, Ministry of Power)

5.3 Viability gap funding (VGF) for long-duration storage, offshore wind and PSP

India is using viability-gap funding (VGF) to accelerate technologies that are system-critical but currently cost-challenged. In September 2023 a VGF scheme for BESS was approved, with 13.22 GWh under implementation and a budgetary allocation of INR 3,760 crore, followed by another approved scheme in June 2025 for 30 GWh with INR 5,400 crore support from the Power System Development Fund (PSDF). Figure 09 depicts IEA projections of increasing share of BESS technologies by 2040 in India occupying one-third of global share.

Fig 10: IEA projections of increase in BESS in India from 2018 to 2040



Source: International Energy Agency (IEA), 2020

For offshore wind VGF will be provided for an initial 1 GW capacity, and ISTS charges are waived for offshore wind projects until December 2032. (Ministry of Power, The Energy and Resource Institute (TERI))

Under the national energy storage roadmap and ministry initiatives, pumps-hydro or pumped storage projects have been recognised as a key storage technology alongside BESS. A new comprehensive VGF proposal being advanced by the Ministry of Power is reported to broaden support to include Pumped Storage Projects (PSPs) under future VGF schemes, although a final scheme is still in planning/approval stages. Whalesbook

Even where direct VGF hasn't yet been formally rolled out for PSPs, the government has issued guidelines to promote PSPs, including procedural support for PSP procurement, and has extended a 100 % waiver of inter-state transmission charges for PSPs whose construction is awarded before June 30 2028 — which significantly improves project economics. Ministry of New & Renewable Energy

Roadmap: BESS integration and scale up (2026–2032)

Targets & finance in place

- CEA projects ~37 GWh BESS by 2027 and ~236 GWh by 2031–32; VGF tranche II (June 2025) supports 30 GWh with ₹5,400 crore from PSDF (₹18 lakh/MWh), including state allocations + 5 GWh for NTPC. Existing tranche brought 13.2 GWh under implementation

2026–2027: "Bankable rollouts"

- Run tariff based bids under VGF II; standardise two hour configurations with 1.5 cycles/day (preferred); 18 month COD timelines; front loaded VGF disbursement (70% by COD) for cash flow

2028–2030: "Markets + operations"

- Enable capacity/availability linked payments and ₹/kWh dispatch products; align with ancillary markets; integrate with MBED to shift net load and cut curtailment

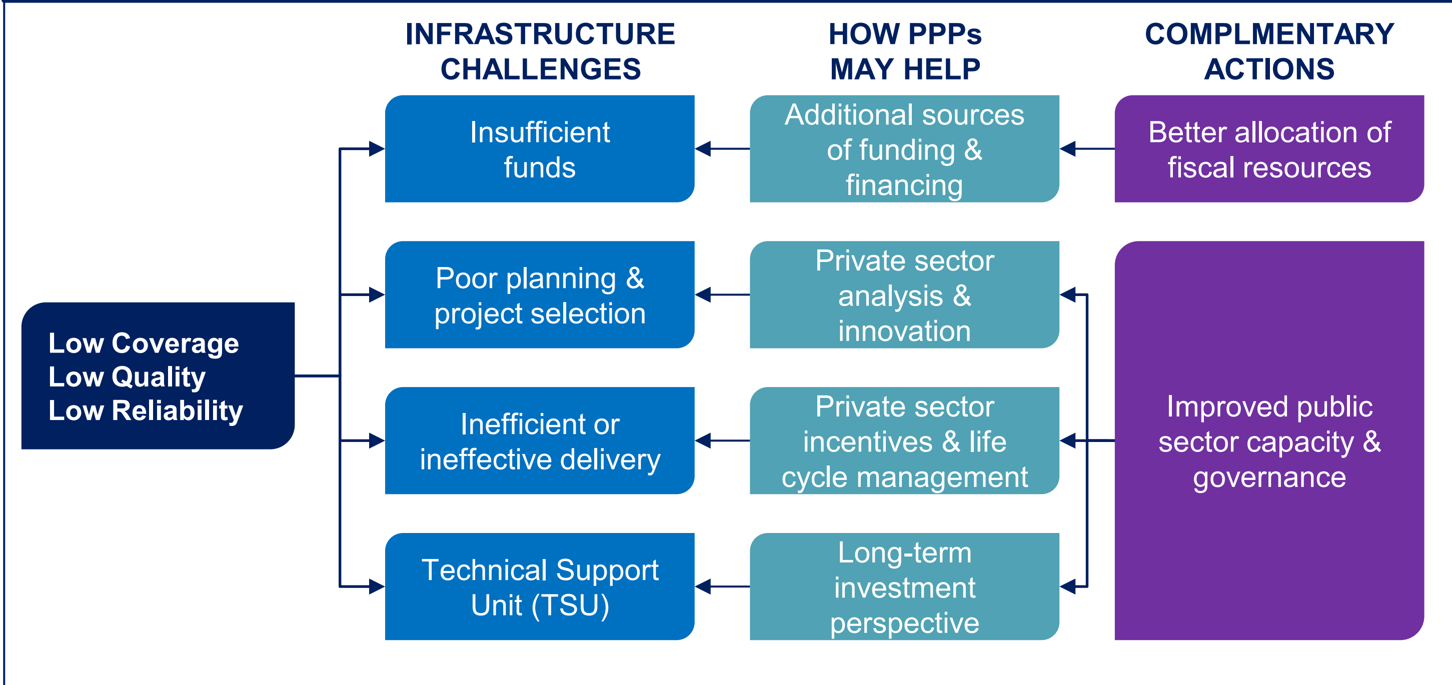
2030–2032: "From projects to portfolio scale"

- Hit 100+ GWh operational on path to 236 GWh; prioritise storage at RE hubs + urban peaks + data centre clusters; measure reduced curtailment and evening peak coverage

5.4 New Public-private partnerships (PPP) and infrastructure investment trust (InvIT) opportunities

As capital needs rise, asset monetisation and risk-segmented vehicles are gaining relevance. InvITs are making inroads as a tool for infrastructure owners to monetise operating assets and for investors to gain exposure to long-duration cash flows, citing activity around Powergrid and renewable-focused InvIT plans alongside Indigrid's performance as an early power-sector InvIT. These structures can recycle sponsor equity from stabilized transmission or renewable assets into new construction, while giving pension funds and insurers access to yield-oriented infrastructure exposure.

Fig 11: Benefits of PPPs for governments



Source: World Bank Group

For greenfield build-out, PPPs remain a complementary pathway where appropriate risk sharing and well-defined contracts can shift upfront capex burden to private partners, while public instruments (including VGF) improve viability. NITI Aayog's PPP division positions PPPs as a preferred mode for infrastructure delivery, with evolving VGF guidelines that can support private participation in eligible sectors. (IEEFA India, NITI Ayog, ICLEI - Local Governments for Sustainability)

06

POWERING A CLEAN AND ABUNDANT ENERGY FUTURE

6.1 Pathways to 500+ GW RE by 2030 and net-zero by 2070

India's official target is 500 GW of non-fossil capacity by 2030 and net-zero by 2070. Government planning notes that SECI has identified 181.5 GW Renewable Energy Zone (REZ) potential and that a CEA report has been prepared for integrating over 500 GW of non-fossil generation by 2030. With current non-fossil fuel capacity sitting at 228 GW in FY25, India would need to add 54.4 GW of non-fossil capacity annually through 2030 to reach the 500 GW milestone. To meet 500 GW and 50% energy from renewables by 2030 is feasible but very challenging, with the key requirement being large-scale storage and flexibility of generation sources. CEEW-AEEE analysis finds India is on track to meet its 2030 NDC (nationally determined contribution) emissions-intensity target, but net-zero by 2070 will require additional interventions such as carbon pricing, power-pricing reforms and stronger energy efficiency and lifestyle measures. (Ministry of Power, TERI, CEEW)

6.2 Quantified risk exposures in delivering the 2030-32 pathway

Transmission expansion (to support 500–600 GW RE by 2030–32)	
Baseline & targets	• CEA's National Electricity Plan (Transmission) envisages ~1,91,000 ckm of new 220 kV+ lines and 1,270 GVA of transformation capacity (2022 23 to 2031 32), plus 33 GW of HVDC bi poles. Inter regional capacity rises from ~119–120 GW (2024) to 168 GW by 2032. Total capex > INR 9.15 lakh crore through 2032
Key quantified exposures	• Inter regional capacity build gap: 48–49 GW must be added by FY2032 (~6 GW/yr on average from FY2024 baselines). Any 1 year slippage of 20% in planned additions could leave ~1.2 GW of inter regional transfer unrealized in that year, increasing curtailment risk in high RE states • Supply chain concentration in HVDC: Critical LCC/VSC components are concentrated with three OEMs (GE, Hitachi Energy, Siemens), leading to systemic execution bottleneck such as longer lead times and price rigidity • Investment intensity: With INR 9.15 lakh crore planned, any 5% cost escalation adds ~INR 45,750 crore to the program, pressuring tariffs or timelines
Mitigation	• Standardize ratings/specs for VSC platforms; relax import rules where domestic capacity is a bottleneck; allow targeted imports for 765 kV class equipment for time critical corridors

MBED Rollout

Baseline & targets	• Market coupling (DAM) directed for phased rollout by January 2026; shadow pilot showed ~INR 38 crore increase in social welfare and +0.2–0.3% volume gain in DAM; RTM coupling deferred pending experience • MBED potential: ~ INR 14,000 crore / year savings from pan India economic dispatch of thermal and INR 1.5 – INR 4 crore / day state level savings in pilots
Key quantified exposures	• IT/Operations: Coupling adds a central clearing layer. Pilot results suggest welfare gains are modest in DAM (0.3%) initially due to liquidity skew. This quantifies the short run expectation management challenge • Contract/settlement frictions: Transition from PPA bound self scheduling to pooled dispatch requires ring fenced capacity payments and CfD/true up, a known implementation risk identified in MBED literature
Mitigation	• Phased path: DAM coupling now → RTM coupling later → MBED pilots starting with most schedulable ISGS fleets; align with GNA and ancillary services evolution

Offshore wind execution

Baseline & targets	• Zero commissioned capacity as of early 2026; government aims for 30 GW by 2030 with 37 GW auctions planned across models (A/B/C). VGF approved for 1 GW (INR 6,853 crore) plus INR 600 crore to upgrade two ports; SECI issued a 500 MW tender (Gujarat) and is readying ~4 GW (Tamil Nadu)
Key quantified exposures	• Greenfield learning curve: From pre survey to COD, first wave projects typically span ~5–7 years globally; India's first 1–1.5 GW may see schedule/capex over runs until local supply chains (jack up vessels, offshore substations, subsea cable spread) mature • Auction pipeline vs. execution bandwidth: 37 GW auctions planned by 2030 but no installed base yet; risk of bunching in construction years 2028–31 if early bids cluster
Mitigation	• Lock port upgrades early (VGF INR 600 crore), sequence offshore substations/cables with PGCIL tenders, and ring fence evacuation in NEP(T) corridors (CEA plan integrates 10 GW offshore)

Critical Mineral Vulnerabilities	
Baseline & targets	• India currently faces high import dependence and supply concentration risks. Its target is to achieve supply security and self-reliance by 2030 through domestic exploration, global sourcing, recycling, and value-chain development.
Key quantified exposures	• India remains 100% import dependent for lithium, cobalt, nickel; refining is globally concentrated (China dominant), creating strategic exposure for batteries, motors, and electronics • National Critical Mineral Mission (NCMM, 2025) launched to coordinate exploration (1,200 projects to 2030 31) and centralize auctions for 24 critical minerals now listed in the MMDR Act schedule • Imports of critical minerals have risen ten fold (FY15–FY24); continued demand growth is projected - quantifies the "cost of status quo" risk exposure • KABIL's overseas lithium blocks (in Argentina) may take a decade to begin production, underscoring long lead times
Mitigation	• Domestic recycling could supply >40% of India's Li/Ni/Co by 2050, building circularity to cut import risk • NCMM programs + diversified offtake from friendly geographies (IEEFA recommends Australia/Chile/Ghana/South Africa) to reduce single country exposure

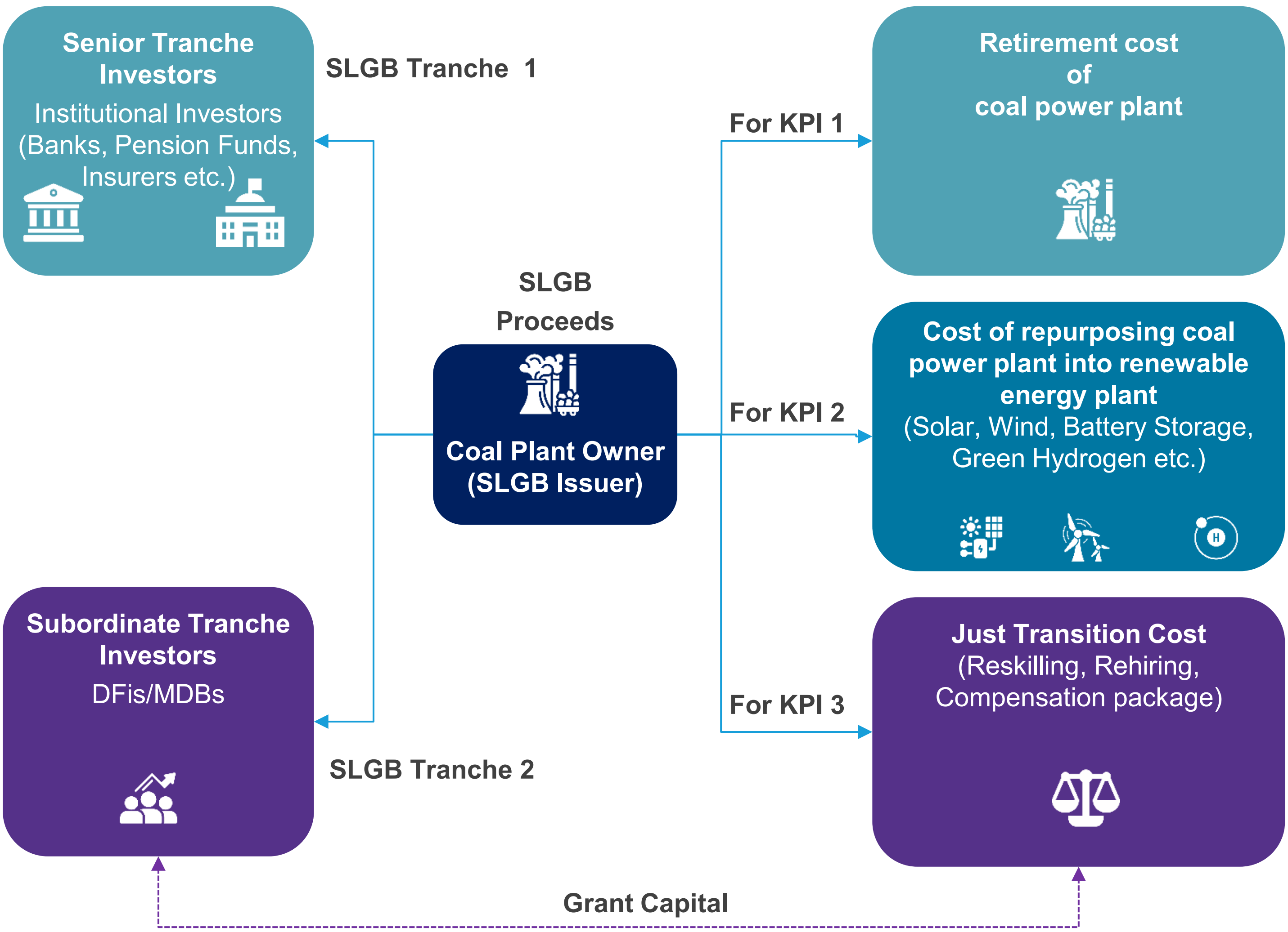
6.3 Managing coal fleet transition - repurpose, retrofit, retire

Coal is expected to play a balancing role in the medium term, but its function shifts from baseload to flexibility provider as renewables scale. CEA regulations mandate thermal units to achieve 55% minimum thermal load (MTL) progressing slowly towards 40%, which requires upgrades to boilers, turbines and control systems and suitable compensation mechanisms for part-load operation and start/stop cycling.

The Ministry of Power advisory to retire units older than 25 years is implemented, 50-60 GW of coal capacity could retire by 2030. India currently has 42 GW of coal plants aged 25+ years, and another 23 GW reaching 25 years by 2032, implying a sizable cohort that could face economic end-of-life decisions this decade. Sustainability-linked green bonds (SLGBs) is a structure grown in popularity to finance early repurposing of technically feasible coal plants into renewable energy assets. It uses KPIs and ring-fenced proceeds tied specifically to coal-to-RE conversion projects to avoid greenwashing. A blended SLGB structure, using concessional capital or guarantees from MDBs/DFIs in a subordinated tranche, is intended to lower borrowing costs enough that savings from cheaper renewable power and avoided coal costs can both cover repurposing capex and support a just transition for affected workers and utilities. (CEA, Ministry of Power, IEEFA)

6.4 Demand-side decarbonization: industry, buildings, transport

Fig 12: Proposed structure for sustainability-linked green bonds (SLGB) to repurpose coal power plants



Source: Institute of Energy Economics and Financial Analysis

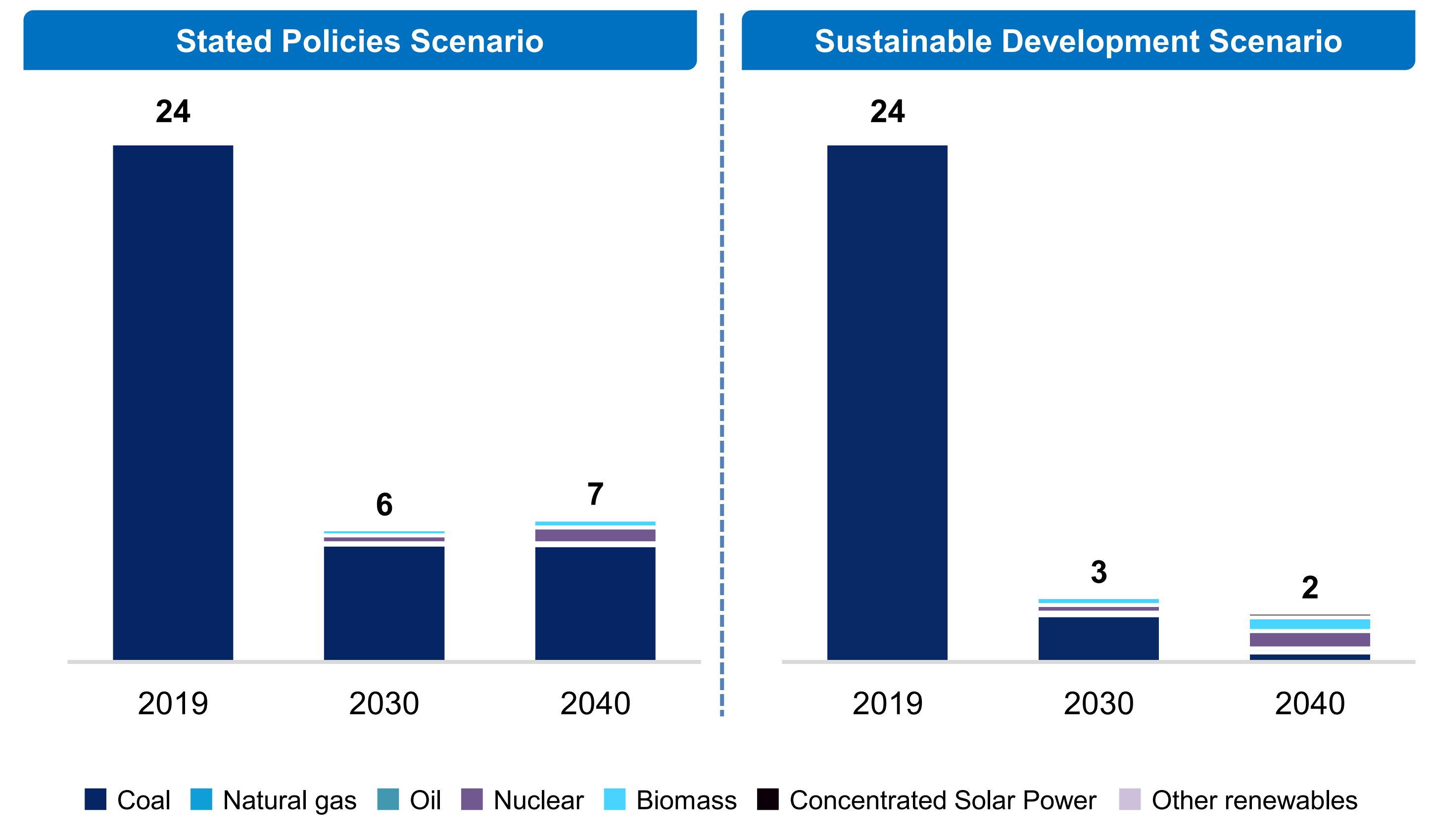
Industry, buildings and transport will determine whether rising electricity demand translates into higher coal burn or accelerated clean electrification. India's heavy industries emit ~920 $MtCO_2$ annually and that decarbonising India's heavy industries could require around 120 GW of renewables by 2030. Buildings consume over 30% of total electricity consumed in the country and that residential electricity consumption could rise to 630–940 TWh by 2032, with air-conditioning a key driver.

This makes building energy codes and efficiency a central decarbonisation lever. Transport sector contributes ~18% of India's total GHG emissions and that decarbonisation is being pursued through biofuel blending, EV adoption and electrification of rail. CEEW-AEEE modelling underscores that energy efficiency and sustainable lifestyles can deliver high absolute emissions reductions and that power-pricing reforms can accelerate rooftop solar adoption in residential buildings. (Ember Energy Case, ECO-NIWAS, EY)

6.5 Water-energy nexus & climate resilience planning

Coal-fired power generation accounts for 80% of India's energy sector water withdrawals, approximately 24 billion cubic meters (bcm) in 2019, with 40% of thermal plants sited in water-stressed or water-scarce regions. The consequences are already material: between 2013 and 2017, water shortages forced repeated thermal shutdowns, with each GW-day of lost generation costing INR 4-10 crore in revenue, while droughts simultaneously suppressed hydro output, creating compound reliability shocks.

Fig 13: Power sector freshwater withdrawal (in bcm) in the Stated Policies Scenario vs Sustainable Development Scenario, 2019-40



Source: International Energy Agency (IEA)

Scenario modelling shows the energy transition itself is the most powerful remedy. Under current stated policies, freshwater withdrawals fall from ~24 bcm to ~6 bcm by 2040 as coal's generation share declines, while an accelerated sustainable development pathway collapses withdrawals further to ~3 bcm (an 87% reduction) driven by aggressive renewables deployment and cooling technology mandates. Critically, however, freshwater consumption diverges. It rises to ~4.2 bcm under stated policies (as nuclear and biomass consume more per MWh) but falls to ~1.8 bcm under sustainable development, underscoring that the type of replacement technology matters as much as the pace of coal phase-down. The forward agenda should be to co-plan energy and water by mandating efficient cooling for all remaining thermal and new hydrogen assets, accelerating low-water renewables, and embedding water-availability stress testing into generation siting and resource adequacy planning. (IEA)

07

POWERING ADVANCED TECHNOLOGY INNOVATION

India's power system is transitioning from analogue infrastructure managed through manual processes to an intelligent, data-driven network. As variable renewables scale toward 500 GW and new loads like EVs and data centres reshape demand patterns, the grid's core challenge shifts from capacity to real-time coordination—making digital technologies not optional add-ons but foundational infrastructure.

7.1 AI and IoT for grid automation, reliability, predictive operations

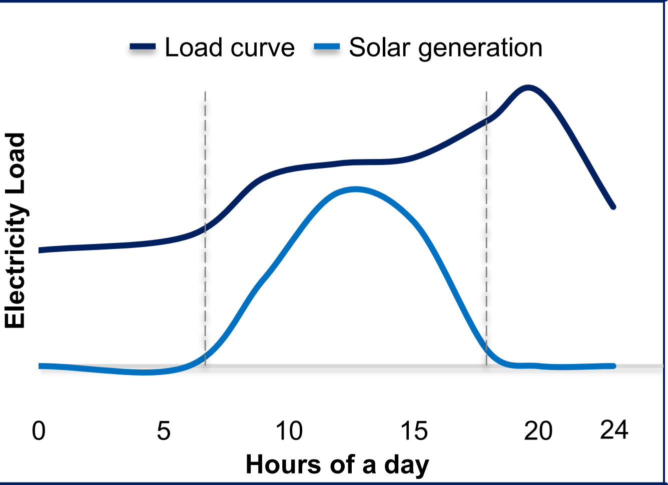
India's transmission and distribution network spans over 500,000 circuit-kilometres as of January 2026 and millions of assets, yet much of it still relies on time-based maintenance and reactive fault management resulting in unplanned outages, equipment failures, and system losses that cost utilities thousands of crores annually. As renewable penetration rises, these challenges intensify because variable generation needs real-time balancing, faster fault isolation, and predictive interventions that manual systems cannot deliver at scale. Power Grid Corp has deployed indigenous AI tools such as PG-AMRIT for predictive asset health diagnostics, PALMS for lifecycle management, and autonomous substation inspection robots across its operations, targeting five focus areas:

- **Predictive Maintenance**
- **Outage Management**
- **Asset lifecycle optimization**
- **Grid Modernization**
- **Load Forecasting**

IIT Jodhpur (Rajasthan) is piloting AI-enabled grid automation with real-time fault detection and demand response. Looking ahead, the convergence of IoT sensor networks feeding AI platforms will shift grid operations from reactive to predictive model, anticipating equipment failures before they occur, dynamically routing power through the most efficient pathways, and enabling autonomous self-healing networks that restore supply within seconds rather than hours. (PowerLine Magazine, Indian Science, Technology and Innovation Portal)

7.2 From Smart Metering to Smart Pricing: Unlocking Demand Response

Fig 14: Mismatch Between Solar Availability and Peak Electricity Demand Under Flat Tariffs



Source: IMD

India's power system has historically charged consumers a flat rate regardless of when they consume, providing no incentive to shift load away from expensive evening peaks or toward periods of abundant, cheap solar generation.

This suppresses demand flexibility, forces costly peaking capacity buildout, and undermines renewable integration. The Government of India's 2023 amendment to the Electricity (Rights of Consumers) Rules introduced Time-of-Day (ToD) tariffs: 10–20% lower rates during eight solar hours and 10–20% higher during peak hours, applicable to C&I consumers (≥10 kW) from April 2024 and all non-agricultural consumers from April 2025.

ToD tariffs become effective immediately upon smart meter installation, directly linking the 4.76 crore smart meters installed to demand-side flexibility. Over time, wider ToD adoption combined with smart meters and automated controls can meaningfully flatten the evening peak by shifting flexible loads - such as cooling, water pumping and EV charging -into solar hours, lowering system peak and deferring some generation and network investments. (Ministry of Power)

7.3 Solar-enabled EV charging stations

India's EV charging network faces a fundamental tension wherein charging infrastructure must scale rapidly (every 3 km in cities, every 25 km on highways under the 2025 policy), but each 350 kW fast charger draws power equivalent to 50–70 households, creating localised grid stress that can destabilise distribution transformers. Without intelligent integration, mass EV adoption risks exacerbating the very peak demand problem renewables are meant to solve.

Table 2: Total public EV charging stations

Year	Total Public EV Charging Stations
2021	452
2022	5,151
2023	11,903
2024	25,202
2025	29,151

Solar-integrated charging stations address this by co-locating PV generation, battery storage, and smart charging algorithms that align EV demand with solar availability absorbing midday surplus when wholesale prices are lowest and buffering evening demand through on-site storage. Vehicle-to-Grid (V2G) technology extends this further: India's 3.5 lakh+ electric cars carry an average 70 kWh battery used only ~5% of the time, representing a massive, distributed storage resource. IIT Bombay and KSEB have launched India's first large-scale V2G field pilot, while ISGF demonstrated V2G feasibility across three Delhi DISCOMs with CEA now drafting reverse-charging guidelines. By 2030, a fleet of 80 million EVs could function as mobile grid batteries charging during solar hours, discharging during evening peaks. This can be made possible if regulatory frameworks, bidirectional charger standards, and DISCOM incentive structures are put in place now. (Servotech, TECell, IIT Bombay PR)

7.4 Blockchain-enabled P2P energy trading

India's rooftop solar market suffers from a structural monetisation gap. Households with solar panels generate surplus power but lack efficient mechanisms to sell it beyond net metering, which offers unfavourable rates and limited scalability. While neighbouring consumers without solar panels continue purchasing expensive grid power. This suppresses rooftop solar adoption and underutilises distributed generation assets. Blockchain-based peer-to-peer (P2P) energy trading offers a solution by enabling prosumers to sell surplus electricity directly to nearby consumers at mutually agreed prices, with smart contracts ensuring transparent, tamper-proof settlement integrated with DISCOM billing cycles. Uttar Pradesh's rooftop solar pilot shows that blockchain-based P2P trading can work in practice, not just in theory. The project used a blockchain platform to record energy trades from prosumer rooftops to neighbouring households and buildings, with the market buy price emerging 43% lower than the prevailing retail tariff, materially improving the value proposition for both surplus generators and buyers. This allowed the state utility to understand how P2P trades affect the distribution network and to define a network tariff that can support wider rollout across the state. On the back of these results, the state regulator amended its tariff order to direct all Uttar Pradesh utilities to implement controlled P2P trading, making it the first state to explicitly enable such a framework in India. The pilot has since been recognised by global digital innovation awards, positioning it as a reference model for other states that want to scale rooftop solar by turning prosumers into active market participants rather than passive net-metered customers. Apart from UP other successful pilots across Delhi and Kolkata prompted UPERC and DERC to start building P2P trading guidelines. (PowerLine, Power Ledger WhitePaper)

7.5 Digital twins for generation & storage assets

As India's renewable portfolio grows, the complexity of managing thousands of geographically dispersed solar parks, wind farms, and battery storage systems exceeds what traditional monitoring can handle. Equipment degradation goes undetected, curtailment events are diagnosed after the fact, and suboptimal dispatch erodes returns. Digital twin technology addresses this by creating virtual replicas of physical assets that integrate real-time sensor data with AI-driven predictive models. Before a project breaks ground, digital twins simulate 25-year energy yields by integrating weather variability, terrain characteristics, and grid limitations, flagging curtailment risks and environmental concerns that require design adjustments. During operations, they enable predictive maintenance by modelling inverter temperature profiles, transformer oil diagnostics, tracker motor vibrations, and panel-level degradation rates, pre-empting failures that would otherwise cause costly unplanned downtime. IIT Jodhpur is developing AI-driven digital twin systems specifically for Indian solar plants, targeting optimal condition monitoring and energy management. The India Energy Stack concept envisions digital twins of entire grid systems enabling advanced simulation and planning, while utilities and IPPs increasingly adopt twin-enabled platforms for battery storage dispatch optimisation, balancing cost efficiency with reliability across portfolios. (PowerLine)

08

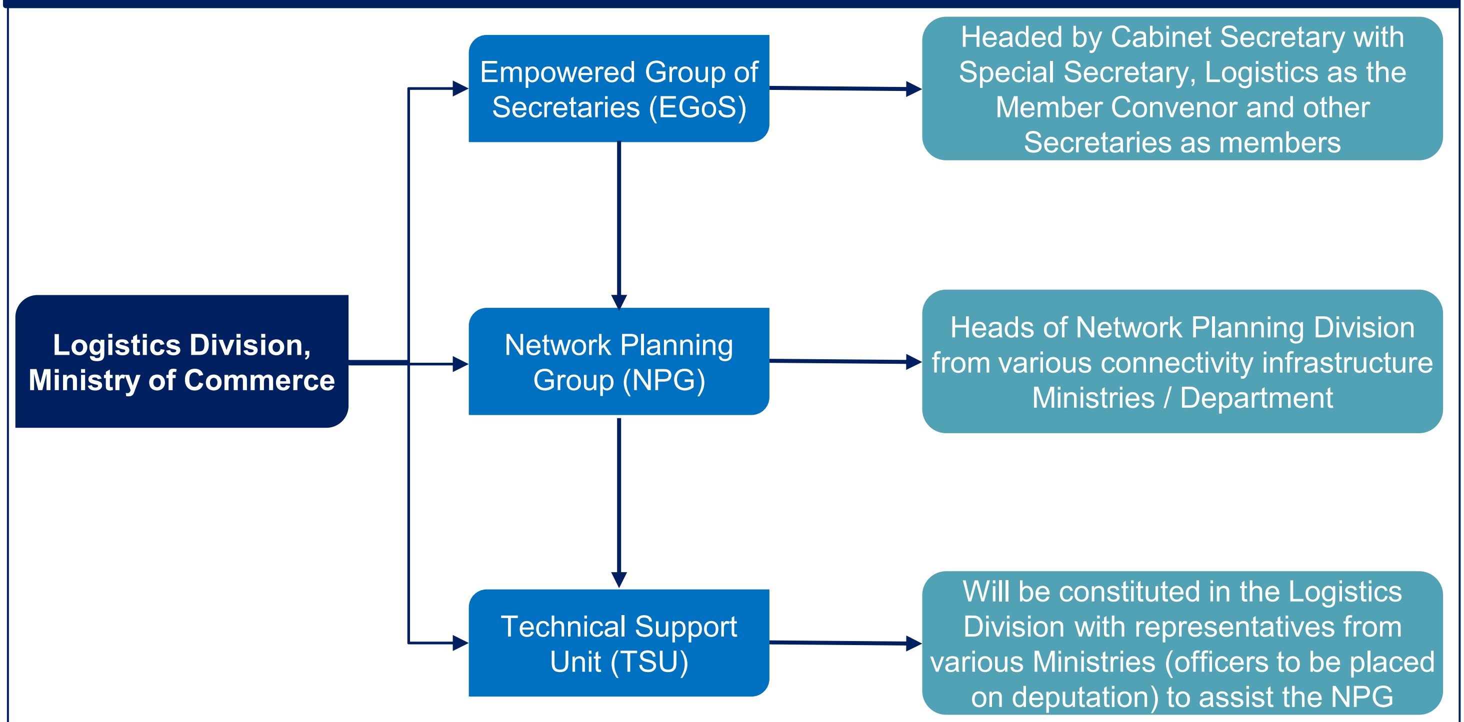
POWERING EASE OF DOING BUSINESS

India's power transition needs $450 billion by 2032. Mobilizing this capital requires regulatory frameworks that match the pace of technology deployment. Land, permits, tariffs, market access, and approvals remain the five friction points that delay projects, deter investors, and inflate costs.

8.1 Streamlined land acquisition and permitting frameworks

Land acquisition remains the single largest cause of renewable energy project delays in India. There have been instances of delay in receiving NOCs, even after a mandated 60-day timeline. PPA signing delays now affect 45 GW of awarded capacity across Rajasthan, Andhra Pradesh, Karnataka, and Madhya Pradesh. Transmission projects take up to three years while associated solar parks commission in 15 to 18 months, stranding generation assets without evacuation. The PM Gati Shakti National Master Plan addresses this through a unified digital platform that aligns ministries on location, clearances, and connectivity. Its governance framework, built around an Empowered Group of Secretaries, a Network Planning Group, and a Technical Support Unit, is designed to coordinate decisions and shorten approval cycles for multi-agency projects.

Fig 15: Governance framework of PM Gati Shakti National Master Plan



Source: Ministry of Commerce and Industry, GoI

Environmental clearance timelines have already compressed from 600 days to 162 days through mandatory online processing. States like Gujarat and Rajasthan offer single-window clearances and designated solar energy zones with pre-acquired land. The forward push must extend this model nationally so developers can move from auction to construction within weeks, not years. ((CERC, CEA, PowerLine, PM Gati Shakti))

8.2 Tariff rationalization and market-based economic dispatch

India's tariff structure is distorted by opaque cross-subsidies. Industrial consumers pay artificially inflated rates to subsidise agricultural and residential categories. This penalises manufacturing competitiveness and deters energy-intensive investment. The Electricity (Amendment) Bill, 2025 mandates cost-reflective tariffs and full elimination of cross-subsidies for manufacturing enterprises, railways, and metro rail within five years. State governments must pay subsidies transparently through direct transfers rather than loading them onto industrial bills. In parallel, Market-Based Economic Dispatch will replace state-level scheduling silos with a national pool. The cheapest generators across India get dispatched first to meet system demand.

Analysis shows MBED can save INR 14,000 crore per year (6% of thermal power plant variable cost) through efficient thermal dispatch alone. Pilot runs indicate daily savings of INR 1.5 to 4 crore across individual states like Maharashtra and Tamil Nadu. Together, tariff reform and MBED create the conditions for a competitive, transparent wholesale market aligned with India's "One Nation, One Grid, One Price" vision. (PIB notes, Berkeley Lab (US Gov), RMI)

Roadmap: Market coupling → MBED (2026–2030)

2026 (H1–H2): “Coupling first”

- Operationalise Day Ahead Market coupling (round robin MCO among IEX/PXIL/HPX; Grid India as backup). Publish KPIs: welfare gains, cleared volumes, curtailment, price dispersion
- Begin shadow pilot for TAM; keep RTM coupling deferred pending DAM learnings

2027: “Pilot MBED on schedulable fleets”

- Launch MBED Phase 1 pilots on ISGS thermal + storage co optimisation; preserve PPA capacity charges via CfD/true up; integrate with GNA and ancillary services. Track cost savings vs SCED baseline

2028–2029: “Scale & integrate”

- Expand MBED participation to additional state GenCos/IPP portfolios; harmonise settlement systems and market power mitigation rules; run resource adequacy constructs in parallel

2030: “National MBED steady state”

- Move from pilots to national MBED for day ahead energy; reserve services co optimised; evaluate zonal pricing if persistent congestion appears under GNA. Target savings: continue to reference the ₹14,000 crore/yr upper bound as the policy “north star,” while reporting realised gains from pilots

8.3 Open access and retail competition expansion

For decades, Indian electricity consumers had few DISCOMs as options controlling both the network and the supply of power. This suppressed competition, inflated costs, and left large consumers subsidising inefficient procurement. The Green Energy Open Access Rules 2022 reduced the eligibility threshold from 1 MW to 100 kW. Approval must be granted within 15 days or is deemed approved automatically. A single-window national portal now processes all applications transparently. Results have been significant. The GEOA market has attracted new developers such as Kalpa Power, JSW Energy and Ampyr Energy, in addition to established companies like ReNew Power and Avaada Energy. The regulatory support provided by GEOA has spurred rapid growth in the C&I open access market, achieving a compound annual growth rate of 46% from the fiscal year (FY) 2022 to FY2024, with cumulative capacity reaching 18.7 gigawatts (GW) by the end of FY2024. Twenty-eight of 29 states have adopted the framework. The Draft Electricity (Amendment) Bill, 2025 goes further. It mandates non-discriminatory open access to shared distribution networks, eliminating the need for costly parallel infrastructure. State Commissions may exempt DISCOMs from the universal service obligation for consumers above 1 MW, enabling large users to procure power directly from generators or exchanges. This structural shift moves India from monopoly supply toward genuine retail competition. (Ministry of Power, IEEFA, Electricity Amendment Bill)

Roadmap: Green Open Access (GOA) market evolution (2026–2030)

Where we are

- After 2022 Rules + 2023 amendments, 28 of 29 jurisdictions have adopted or drafted regulations; C&I open access cumulative capacity reached ~18.7 GW by FY2024, with 90% YoY jump in annual installations; Gujarat and Rajasthan lead recent additions

2026: “Harmonise and digitise”

- Enforce 15 day deemed approval timelines; unify eligibility at 100 kW; fix GOAR portal SLDC/DISCOM sync issues; publish per state banking & charge matrices for transparency

2027–2028: “Scale beyond large C&I”

- Introduce MSME aggregation (multi connection pooling already enabled); standardise banking settlement windows; expand ISTS OA options and PX based GOA products

2029–2030: “Retail competition readiness”

- Reduce state level deviations; converge on charge structures; prepare for Draft Electricity Amendment provisions on non-discriminatory network access and retail competition in large user segments. Track penetration beyond “≥1 MW club

8.4 Accelerated approval pathways for green technologies

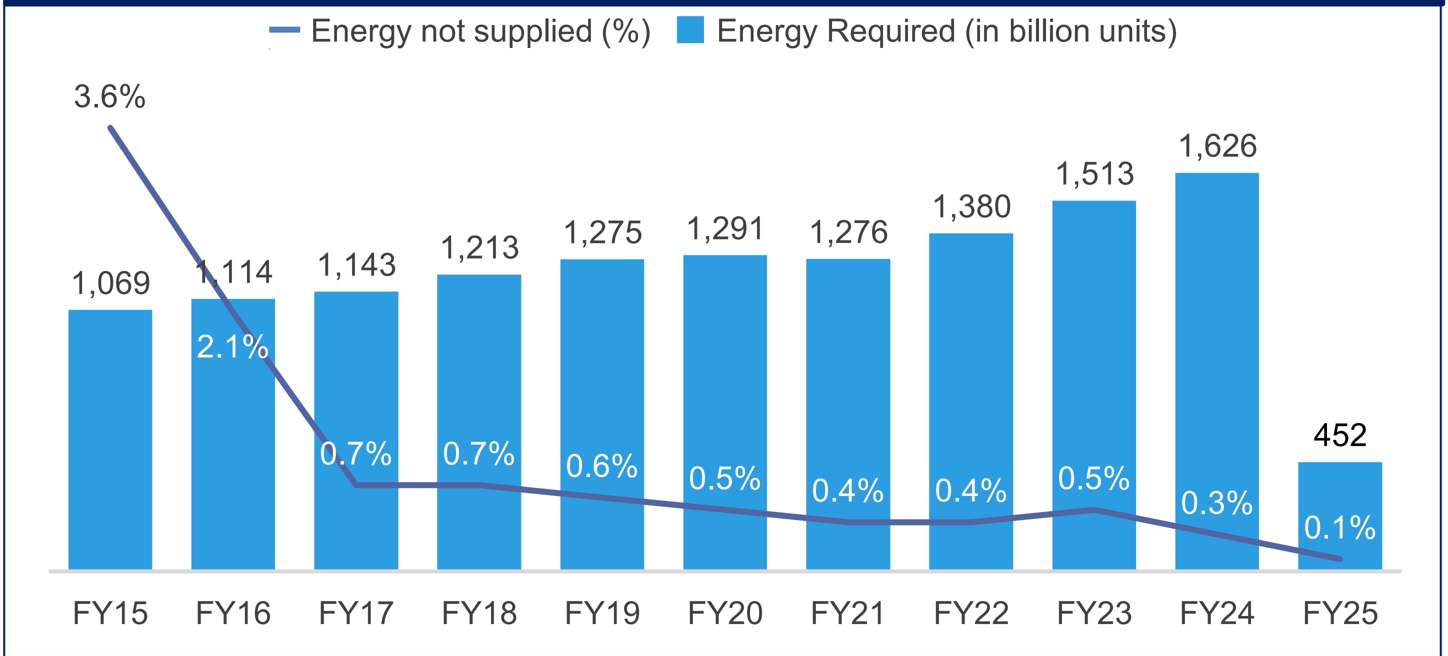
Green technology deployment in India often stalls not due to economics but due to approval timelines. Forest clearances, wildlife NOCs, grid connectivity permissions, and land-use conversions each operate on independent tracks with no synchronisation. The result is that projects miss scheduled commercial operation dates. MNRE and the Ministry of Power have recently extended commissioning timelines for affected renewable projects, but this treats the symptom rather than the cause. Several structural solutions are now in motion. The PM Gati Shakti digital platform integrates clearances across ministries into a single dashboard with real-time tracking. MNRE has exempted SEZ and EOU-based renewable plants from ALMM requirements for green hydrogen production through December 2030. The Green Open Access Registry provides a unified portal for renewable procurement approvals. The Draft Electricity Bill 2025 empowers CERC to introduce market-based mechanisms for renewable integration and strengthens RPO compliance with penalties of 35 to 45 paise per unit for shortfalls. (MNRE PR, PRS India)

09

POWERING INCLUSIVE ENERGY ACCESS

9.1 Last-mile distribution strengthening for rural and peri-urban markets

Fig 16: Power supply in rural areas of India (in billion units)



Source: Ministry of Power

Although India has been able to supply 99.99% of demand from rural India, connection alone does not guarantee reliable supply. Rural feeders still suffer 8 to 12 hour outages in many states. Voltage fluctuations damage appliances and deter productive use. AT&C losses nationally have fallen from 22.62% in FY14 to 16.16% in FY25, but several states remain above 25%. The Revamped Distribution Sector Scheme (RDSS) addresses this with INR 3.03 lakh crore over five years (2021 to 2026) with projects worth INR 2.83 lakh crore already sanctioned. The distribution infrastructure works accounts for INR 1.53 lakh crore of the total fund which will help in replacing frayed conductors, laying aerial bunched cables, upgrading transformers, and segregating agricultural feeders. Goa has made highest physical progress (77%) in loss reduction works under RDSS followed by West Bengal at 53%. Prepaid smart metering under RDSS will enable real-time energy accounting at feeder and transformer levels. This shifts the paradigm from reactive complaint resolution to predictive maintenance and targeted loss reduction with the goal being curtailing the AT&C losses at 12-15% on a national level. (Ministry of Power, Energy Department - Government of MP, Lok Sabha)

9.2 Reliable, affordable electricity underpins manufacturing expansion

Indian manufacturers pay among the highest industrial tariffs globally. Cross-subsidies inflate industrial rates well above the average cost of supply. Firms respond by reducing grid purchases, investing in captive generation, or relocating to cheaper jurisdictions. This directly undermines "Make in India" competitiveness. The Economic Survey 2025-26 recommends eliminating cross-subsidies for manufacturing within five years. The Draft Electricity (Amendment) Bill, 2025 codifies this by mandating cost-reflective tariffs and enabling direct procurement by industrial users. Critically, it protects subsidised tariffs for farmers and low-income households through transparent budgeted transfers under Section 65. The Draft National Electricity Policy 2026 reinforces this with an index-linked automatic tariff revision mechanism for timely cost recovery. The net effect is a phased transition from hidden cross-subsidies to transparent, targeted support. Industry gets competitive power. Vulnerable consumers retain protection. DISCOMs move toward financial sustainability. (MNRE, Ministry of Power, PIB)

9.3 Distributed renewable energy for MSMEs, agriculture, cold chain

Nearly 65% of India's population lives in rural areas. Grid supply in these regions is often intermittent and unsuitable for productive use. This forces farmers onto expensive diesel pumps. It leaves cold chains broken and food wastage at unacceptable levels. Distributed renewable energy technologies offer a viable solution. Just 12 market-ready distributed renewable energy (DRE) technologies can impact 37 million livelihoods and generate $48 billion market opportunity.

Table 3: 12 Mature DRE livelihood technologies in India

DRE Livelihood Technology	# of Livelihoods Impacted (Million)	Market Potential (Billion USD)
Vertical fodder grow unit	11.9	1.8
Higher capacity pump	8.2	26
Cold storage	4.3	2.5
Micro pump	3.4	2.0
Dryer	3.4	2.3
Grain milling	1.9	8.7
Loom	1.2	1.2
Small refrigerator / deep freezer	1.2	1.5
Small horticulture processors	1.1	0.8
Charkha	0.4	0.2
Bulk milk chiller	0.1	0.8
Silk reeling machines	0.1	0.03
Total	**37**	**48**

Solar cold storage addresses the missing link in agricultural supply chains where unreliable power has historically made rural cold chain infrastructure unviable. Solar dryers, milling machines, and silk reeling units are already operational across states like Odisha, Rajasthan, and Uttar Pradesh. 71% of surveyed DRE users experienced income increases, with a typical 35% rise from a baseline of INR 80,000. Farmer cooperatives can own and manage these assets collectively, achieving scale while distributing benefits. (CEEW, CEEW)

9.4 Social equity frameworks for tariff design

Tariff design in India has historically used blunt cross-subsidies. Industrial and commercial consumers pay inflated rates to fund below-cost supply to agriculture and households. Wealthy urban households receive the same subsidised rate as vulnerable rural families. The Economic Survey proposes a more progressive structure. Lifeline tariffs would protect basic consumption for the poorest. Direct benefit transfers would replace opaque cross-subsidies. The Electricity (Amendment) Bill 2025 preserves state governments' authority to subsidise farmers and eligible consumers under Section 65 while requiring these subsidies to be budgeted transparently. This means states must explicitly allocate funds rather than hide costs within DISCOM balance sheets. Phased tariff increases, consumption-based quotas for subsidised categories, and voluntary exclusions for higher-income households can improve targeting. The framework of the bill is built around the following principles:

- ***Progressive reduction of cross-subsidies and ensuring tariffs don't fall below 50% of average cost of supply***
- ***Cost-reflective tariffs with annual index-linked revision so that distribution utilities remain viable without arbitrary subsidies***
- ***Proposals for differential pricing (peak vs off-peak) aligned with smart utilities and long-term cost recovery***
- ***State-centric tariff regulation with targeted performance incentives***

The result is a framework where affordability is preserved for those who need it most while the cross-subsidy burden on industry shrinks progressively. (Times of India, Ministry of Power, Ministry of Power)

10 POWERING ELECTRICITY'S FUTURE WORKFORCE

10.1 New capability clusters: data science, power electronics, hydrogen tech

India's energy transition creates unprecedented demand for specialized technical capabilities. The National Green Hydrogen Mission targets 600,000 professionals by 2030. Grid operators increasingly need data analytics expertise for managing variable renewable flows. Power electronics specialists become essential as bidirectional energy systems proliferate. These requirements reflect fundamental shifts in how electricity systems operate. Current training infrastructure shows promising early momentum. The Skills Council for Green Jobs has trained over 5 lakh candidates including 1 lakh in solar and other renewable energy domains. Leading IITs partner with industry to deliver advanced electrolyzer training programs. Degree apprenticeship models now combine formal education with hands-on operations. These initiatives bridge theoretical knowledge with practical competence.

The National Credit Framework enables industry to co-develop qualifications aligned with emerging needs. Battery storage deployment toward 200 GWh by 2030 drives demand for specialized technicians. Hydrogen production scaling to 5 million tonnes annually creates premium wage opportunities. Data science roles expand rapidly as AI-driven grid optimization becomes standard practice. By 2030, these three capability clusters will anchor India's competitive advantage in clean energy deployment. Universities establishing hydrogen Centres of Excellence will incubate 50 startups over five years. This integrated approach positions India to meet both domestic requirements and export skilled professionals. (MNRE, IEA)

10.2 Reskilling thermal workforce for RE & storage

India's power generation mix demonstrates remarkable diversification momentum. Non-fossil capacity reached 262 GWh by November 2025, exceeding 51 percent of total installed capacity. This achievement arrived five years ahead of Paris Agreement commitments. Coal generation growth moderated to 2.8 percent in FY25 despite rising electricity demand. These trends signal managed transition rather than abrupt disruption.

Approximately 13 million livelihoods connect directly or indirectly to coal mining and thermal generation. Their skills in plant operations, maintenance, and safety protocols transfer readily to renewable systems.

Table 4: Estimated workforce in fossil fuel and allied sectors (in millions)

Sector	Informal Employment	Formal Employment	Total
Coal mining	1.8	0.8	**2.6**
Coal-based thermal power*	0.05	0.13	**0.18**
Iron and steel	2.6	0.3	**2.9**
Cement	1.2	0.2	**1.4**
Oil and gas excluding refineries^	NA	0.12	**0.12**
Refineries	0.08	0.04	**0.12**
Fuel retail	0.96	0.14	**1.10**
LPG distribution	0.01	0.09	**0.10**
Fertiliser#	0.2	0.02	**0.22**
Automobile**	NA	NA	**12.8**
Sum total	**6.9**	**1.8**	**21.5**

NTPC targets 60 GW renewable capacity by 2032 alongside thermal operations. This hybrid strategy creates pathways for workforce evolution. Coal India implements training programs preparing workers for solar sector roles. State agencies track regional green job demand and customize curricula accordingly.

Battery storage may create 30,000 direct jobs annually as deployment reaches 50 GWh by 2028. Thermal operators transition to hybrid facility management overseeing integrated generation portfolios. Operations and maintenance roles in renewables may employ 500,000 workers by 2030. Just transition policies ensure employment continuity while accelerating decarbonization goals. The approach recognizes that workforce transformation enables rather than impedes energy transition. Geothermal and modern bioenergy sectors absorb thermal expertise with minimal retraining requirements. (International Forum for Environment, Sustainability and Technology, CEEW)

10.3 Academia–industry collaboration models

India's research expenditure at 0.6% of GDP suggests significant scope for enhanced university-industry partnerships. Academic institutions possess deep theoretical expertise while industry controls practical deployment insights. Bridging this gap accelerates innovation commercialization. Recent initiatives demonstrate effective collaboration frameworks emerging across the energy sector.

IIT Kanpur and Harcourt Butler Technical University jointly established a Centre of Excellence for Green Hydrogen. This facility will incubate 50 startups over five years. IIT Madras partnered with Hyundai to create a 65,000 square foot hydrogen innovation center. Nineteen IITs signed agreements with the University of Groningen for faculty exchanges. TeamLease Degree Apprenticeships combine paid industry experience with formal academic credentials. These models prove that structured collaboration yields practical outcomes.

The Research Development and Innovation Fund allocates INR 1 lakh crore to catalyze deeper linkages. Companies co-develop curricula under the National Credit Framework ensuring industry-relevant competencies. Semester-long utility internships become mandatory for engineering students. HSBC funds an innovation program at IIT Bombay advancing green hydrogen catalyst research. Research translates rapidly from laboratory concepts to commercial deployment. This positions India as a preferred destination for clean energy R&D investment. (Forbes, ToI, Fuel Cell Works, Dept of Science & Tech, Green Hydrogen Innovation Center,

10.4 Building a vibrant energy innovation ecosystem

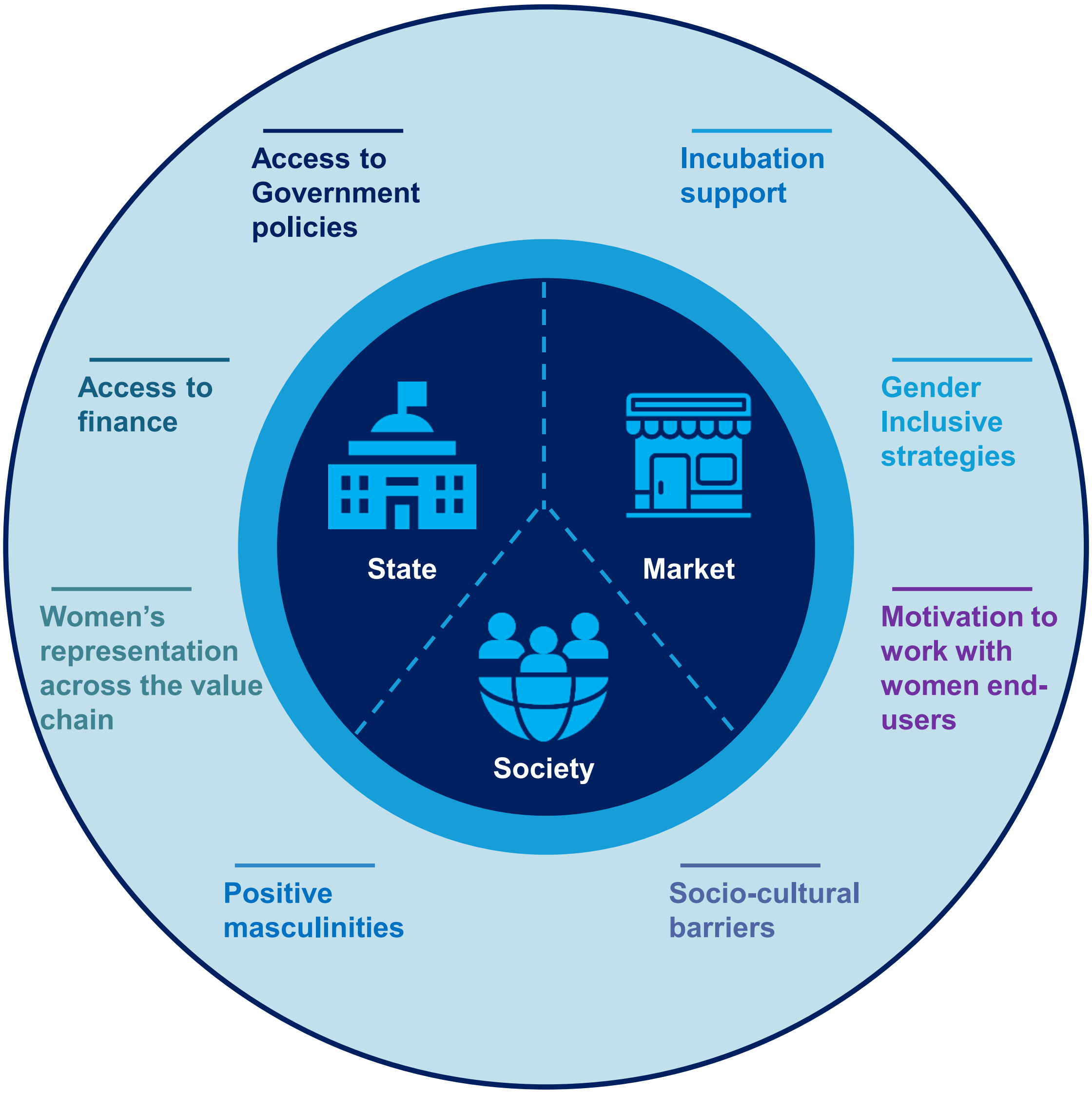
India's startup ecosystem ranks third globally yet energy hardware innovation remains underrepresented. Deep-tech ventures receive 77% less funding than software-focused peers as of 2024. This gap reflects perceived technology risk and longer capital return horizons. Recent policy interventions demonstrate government commitment to reversing these patterns. Startup India Fund of Funds 2.0 channels INR 10,000 crore through venture capital into deep-tech ventures. Regulatory sandboxes permit controlled testing of novel storage technologies. The National Semiconductor Mission positions India within global power electronics supply chains. These initiatives create enabling conditions for hardware innovation to flourish.

Public procurement policies will reserve 20% of tenders for indigenous innovation by 2027. Technology Business Incubators at IITs target commercialization of 500 energy patents annually by 2030. The Green Hydrogen Innovation Partnership accelerates electrolyzer technology development. Energy Systems Catapult UK partnered with IIT Madras for knowledge exchange. India-Netherlands collaboration launched a hydrogen fellowship program building research capacity. These partnerships bring global expertise while developing domestic capabilities. India's innovation ranking will improve toward top 20 countries by 2030. Comprehensive architecture now spans research funding, talent development, and market access. These conditions enable breakthrough energy technologies to emerge and scale within India. (Economic Times, Chambers and Partners, ToI)

10.5 Women's participation in clean energy entrepreneurship

Women comprise over 75% of India's agricultural and allied workforce. Yet only 11% of rooftop solar sector employees are women. 39% of women micro-entrepreneurs own no physical assets at all. This exclusion limits both economic growth and the reach of clean energy adoption.

Fig 17: Society, market and state: Barriers to scale and opportunities for women microentrepreneurs



Source: CEEW

DRE livelihood technologies are changing this. The Powering Livelihoods programme supported 14 enterprises between 2020 and 2023, facilitating 11,500 technology deployments. 71% of beneficiaries were women. Technologies like solar silk reeling machines have 92% women users. Micro solar pumps reach 65% women users. 70% of women users reported increased income, averaging a 33% rise. 89% reported increased participation in community events. The barriers remain significant. Women face limited access to finance, technology awareness gaps, and disproportionate caregiving burdens. Solutions include collateral-free lending for DRE assets, gender-forward incubation programmes, and targeted training. Over 30 women have already accessed low-interest financing through programme partnerships. Scaling this model nationally can unlock women's entrepreneurship as a force multiplier for India's clean energy transition. (IEA, CEEW)

11

TEN STRATEGIC IMPERATIVES FOR BHARAT'S ELECTRICITY LEADERSHIP

Build a future-ready grid

- Expand the "renewables backbone" transmission by accelerating inter-regional corridors, HVDC links, and selective FACTS deployment to move power from RE-rich states to demand hubs while keeping stability margins intact
- Make distribution digital-first, not asset-first by scaling smart meters plus ADMS / DERMS to create real-time visibility of outages, losses, and load-turning AT&C reduction and billing efficiency into the fastest affordability lever
- Scale the flexibility stack (storage + controls) as core infrastructure - BESS, pumped storage, and grid-forming inverters, so RE integration is designed for firm, system-strengthening output (not just variable energy)
- Treat cybersecurity as a reliability requirement by operationalising the CEA cyber regulations, sectoral CERT coordination, and OT-grade monitoring/SOCs as digitalisation deepens across T&D and control rooms

Fix market design and bankability

- Restore DISCOM balance-sheet credibility at the source by locking in loss reduction, narrowing ACS–ARR gaps, and tightening payment security/enforcement so generation, transmission, and storage projects remain financeable at scale
- Replace hidden cross-subsidies with targeted, transparent support (e.g., lifeline/DBT-style protection where needed) while moving steadily toward cost-reflective tariffs that protect competitiveness and utility viability
- Build a more efficient national power market by advancing MBED, expanding open access/retail competition, and simplifying approvals/portals so the cheapest clean power can reach buyers faster with fewer transaction frictions

Capture "Viksit Bharat" upside

- Convert demand growth into an industrial advantage by planning for EVs, data centres, and electrifying industry with local network strengthening plus access to abundant low-cost green power as a competitiveness input
- Win the supply-chain race through domestic manufacturing and standardisation across solar, smart metering/grid automation, HVDC equipment, batteries (including recycling), and electrolyser ecosystems - reducing lead-time risk and import dependence
- Deliver a just, inclusive transition via livelihoods and skills by scaling DRE for MSMEs / agri / cold-chain and enabling women's clean-energy entrepreneurship, while reskilling the thermal workforce and building new capability clusters (data, power electronics, hydrogen)

Our Values - The Avalon EDGE

E — ENTREPRENEURSHIP
Enterprising ownership to transform ideas into pragmatic and profitable solutions

D — DEDICATION TO EXCELLENCE
Commitment to premier quality and highest standards in everything we do

G — GREAT VALUE CREATION
Focus on delivering maximum client impact through innovation and collaboration

E — ETHICAL APPROACH
Respect, fairness, and transparency in all our interactions

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