1. Introduction & Rationale

Context & Goal

India has committed to one of the world's most ambitious clean energy transitions, targeting **500 GW of non-fossil fuel capacity by 2030**, of which approximately **537 GW** is expected to come from **renewable energy (RE)** sources such as solar, wind (onshore and offshore), biomass, and small hydro. This target is not only enshrined in India's Nationally Determined Contributions (NDCs) under the Paris Agreement, but also concretely laid out in planning documents by key Indian agencies including the **Central Electricity Authority (CEA)**, **Ministry of Power (MoP)**, **Central Electricity Regulatory Commission (CERC)**, and the **Central Transmission Utility (CTU)**.

To meet this goal, CEA's December 2022 Transmission Plan has mapped the development of over **50,000 circuit kilometers** of new transmission lines and **433,575 MVA** of substation capacity to integrate the projected 537 GW RE capacity by 2030. Furthermore, **51.5 GW** of **Battery Energy Storage Systems (BESS)** and high-voltage **HVDC corridors** have been planned to ensure system reliability, grid stability, and round-the-clock power supply.

This project focuses on understanding and addressing the **grid-scale challenges and solutions** essential to achieving the 500 GW integration goal—ranging from transmission planning and real-time grid operations to technical, regulatory, and market interventions.

Why It Matters

Achieving a **50% non-fossil energy share** by 2030 is not just a technical milestone—it is central to India's **energy security, economic competitiveness**, and **climate leadership**:

- **Energy Security & Independence**: Reducing reliance on imported fossil fuels will help India manage geopolitical risks and fuel price volatility, especially given the country's growing electricity demand (forecast to reach 366.4 GW peak by 2031–32).
- **Climate Commitments**: Integrating 500 GW of renewables is essential to fulfill India's NDCs and its pledge to reduce carbon intensity by 45% by 2030. This aligns India's development path with global climate goals, while promoting environmental sustainability.
- **Green Investment & Innovation**: The RE transition is expected to drive **₹33.6 trillion** in investments (2022–32), catalyzing economic growth, job creation, and technological innovation in sectors like battery manufacturing, green hydrogen, and smart grids.
- **Global Renewable Leadership**: India's scale and speed of renewable deployment position it as a leader among developing countries. Flagship projects like the **Bhadla Solar Park** and the **Khavda Hybrid Park** are already attracting global attention.

However, the path to 500 GW is complex. India's success will depend on resolving deep infrastructure gaps, regulatory delays, and grid integration challenges, particularly across states like

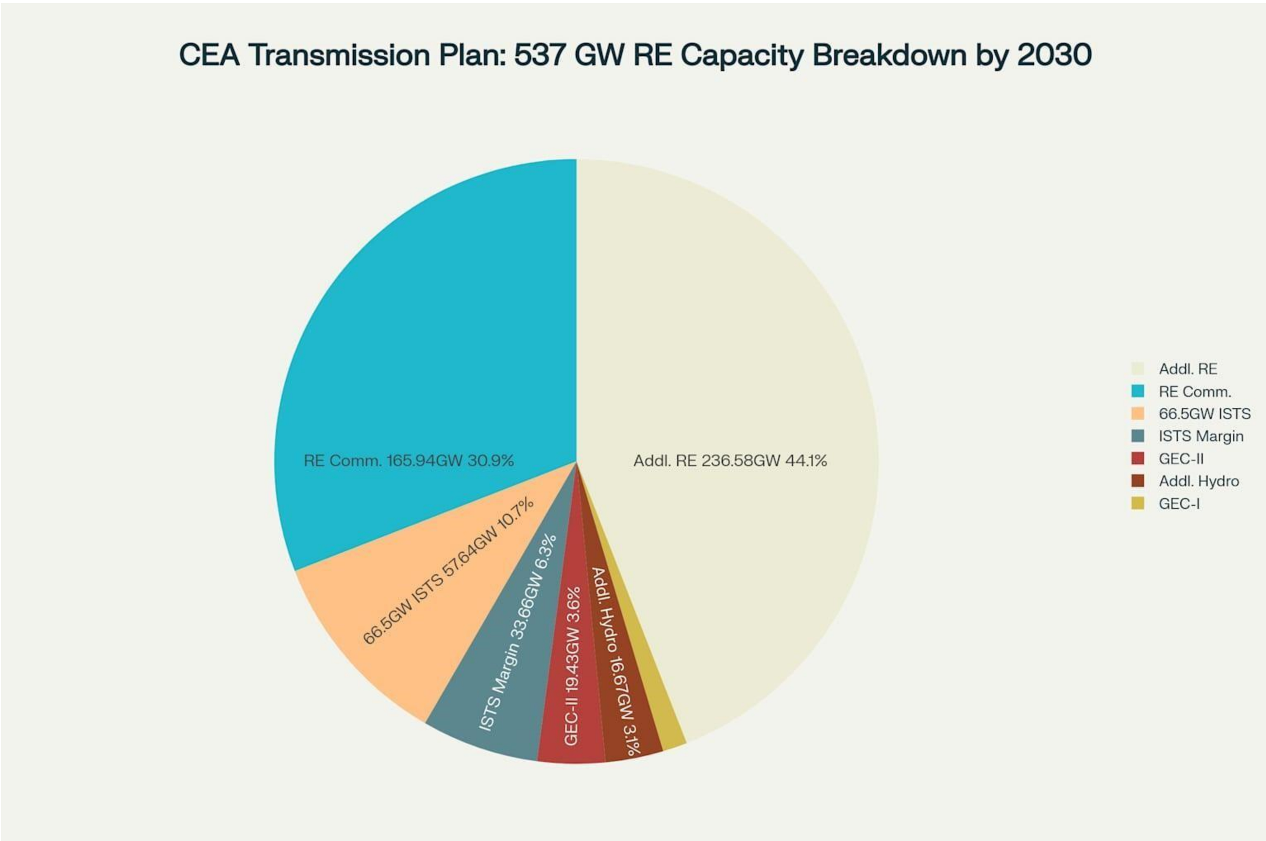
Rajasthan, Gujarat, Tamil Nadu, and Andhra Pradesh. This makes the current moment critical for coordinated action between public agencies, private sector developers, and international partners.

2. Literature & Policy Survey

Section 1:CEA Transmission Plan (December 2022)

Executive Summary

India's Central Electricity Authority (CEA) released its comprehensive transmission plan in December 2022, outlining the roadmap for evacuating approximately **537 GW of renewable energy capacity by 2030**[1][2]. This ambitious plan encompasses the development of extensive transmission infrastructure including **HVDC corridors, 765/400 kV AC lines, and 51.5 GW of Battery Energy Storage Systems (BESS)** to support India's renewable energy targets[3][2].



Overall breakdown of 537 GW renewable energy capacity target showing commissioned, planned, and additional capacity categories

Overall Capacity and Investment Framework

The transmission plan requires a massive investment of **Rs 2,44,200 crores (approximately USD 29.5 billion)** to integrate the targeted renewable energy capacity[3][2][4]. The plan breaks down into several key components:

- **On-shore renewable energy capacity**: 268.68 GW (wind and solar) requiring Rs 2,16,100 crores[5]
- **Offshore wind capacity**: 10 GW requiring Rs 28,100 crores[5]
- **Total additional transmission infrastructure**: 50,890 circuit kilometers (ckm)[5]
- **Additional substation capacity**: 433,575 MVA[5]

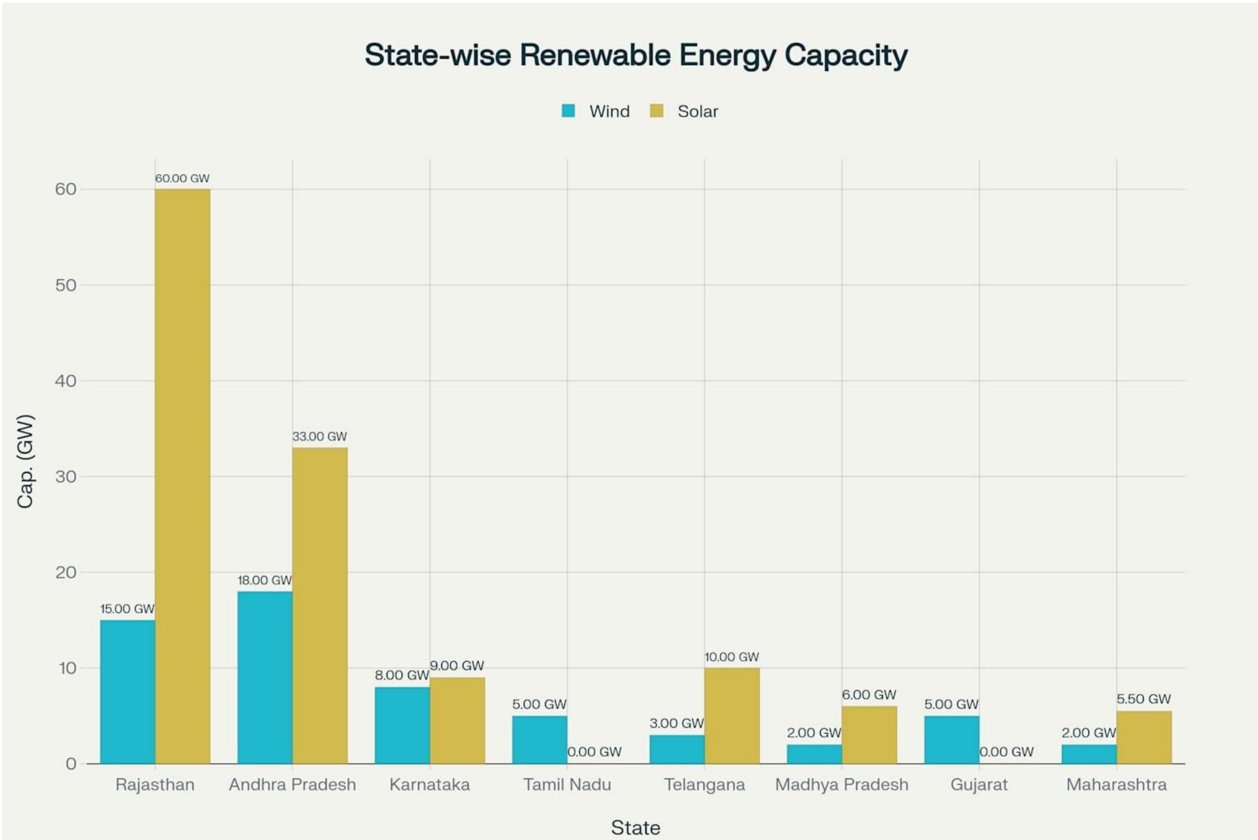
CEA Plan Key Stats Table

CEA Plan Stat.	Value
Overall Capacity Target	
Total RE Target by 2030	537 GW
Currently Commissioned (Oct 2022)	165.9 GW
Additional Capacity Required	371.1 GW
Transmission Infrastructure (50,890 ckm)	
±800 kV HVDC	6,200 ckm
±350 kV HVDC	1,920 ckm
765 kV AC	25,960 ckm
400 kV AC	15,758 ckm
220 kV cable (offshore)	1,052 ckm
Investment Requirements	
On-shore RE transmission	Rs 2,16,100 Cr (88.5%)
Offshore wind transmission	Rs 28,100 Cr (11.5%)
Total investment	Rs 2,44,200 Cr (~USD 29.5b)
BESS and Storage	
Total BESS req.	51.5 GW
Assoc. w/ 181.5 GW RE	43.6 GW BESS

Comprehensive summary table of CEA transmission plan key statistics, infrastructure requirements, and investment breakdown

State-wise Distribution of Renewable Energy Capacity

The plan identifies **181.5 GW of additional renewable energy zones** across eight states, with Rajasthan leading the capacity allocation[1][6]. The state-wise breakdown demonstrates India's strategy to leverage diverse geographical advantages for renewable energy development.

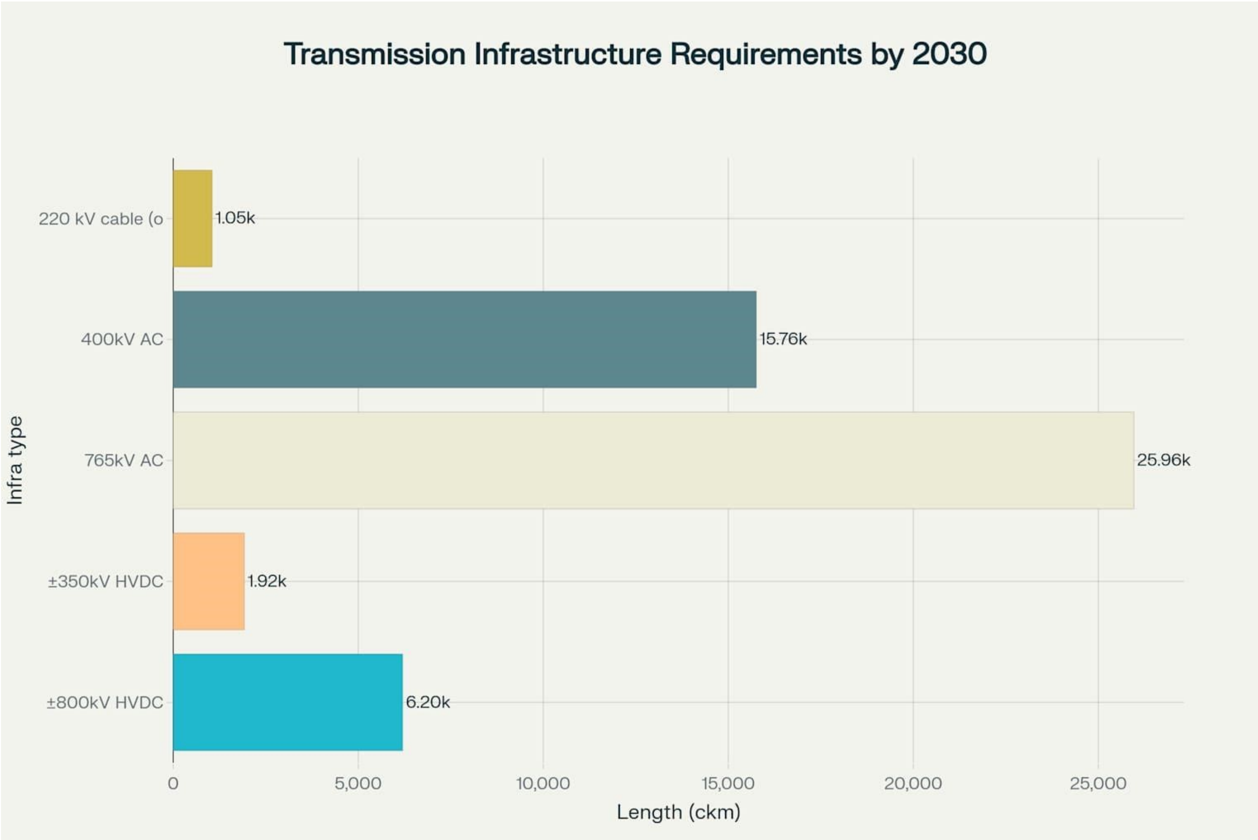


State-wise renewable energy capacity distribution showing wind and solar breakdown across 8 states totaling 181.5 GW ISTS connected capacity

Rajasthan emerges as the dominant renewable energy hub with 75 GW total capacity (15 GW wind + 60 GW solar), followed by Andhra Pradesh with 51 GW (18 GW wind + 33 GW solar)[5][6]. The plan also includes **10 GW of offshore wind capacity** split equally between Gujarat and Tamil Nadu (5 GW each)[7][8].

Transmission Infrastructure Requirements

The transmission system expansion involves multiple voltage levels and technologies to ensure efficient power evacuation from renewable energy zones to load centers[5]:



Transmission infrastructure requirements showing length of different voltage levels needed by 2030

High Voltage Direct Current (HVDC) Systems

The plan includes **8,120 ckm of HVDC transmission corridors** comprising:

- **±800 kV HVDC**: 6,200 ckm with 20,000 MVA capacity[5][4]
- **±350 kV HVDC**: 1,920 ckm with 5,000 MVA capacity[5]

Key HVDC projects include:

- **Bhadla-III to Fatehpur ±800 kV HVDC system** for 20 GW RE capacity in Rajasthan[5]
- **Pang (Leh) to Kaithal ±350 kV VSC HVDC link** for 13 GW Leh RE park[5]
- **Barmer-II to Jabalpur ±800 kV HVDC system** for evacuation from multiple RE zones[5]

Alternating Current (AC) Transmission Lines

The AC transmission infrastructure comprises:

- **765 kV lines**: 25,960 ckm with 274,500 MVA capacity[5]

- **400 kV lines**: 15,758 ckm with 134,075 MVA capacity[5]
- **220 kV submarine cables**: 1,052 ckm for offshore wind projects[5]

Implementation Timeline and Phasing

The 181.5 GW renewable energy capacity will be deployed in three distinct phases, ensuring systematic grid integration and manageable construction timelines[5]:

- **Phase I (by March 2025)**: 56 GW (24 GW wind + 32 GW solar)
- **Phase II (by December 2027)**: 62.1 GW (17 GW wind + 45.1 GW solar)
- **Phase III (by December 2030)**: 63.4 GW (17 GW wind + 46.4 GW solar)

Battery Energy Storage Systems (BESS)

The plan incorporates **51.5 GW of BESS capacity** to address the intermittency challenges of renewable energy and provide round-the-clock power supply[3][9][10]. The BESS deployment varies by state based on renewable energy characteristics:

- **Rajasthan**: 22.5 GW BESS (30% of RE capacity)
- **Andhra Pradesh**: 14 GW BESS (27% of RE capacity)
- **Karnataka**: 3 GW BESS (18% of RE capacity)
- **Telangana**: 3 GW BESS (23% of RE capacity)
- **Maharashtra**: 1.1 GW BESS (15% of RE capacity)

Offshore Wind Infrastructure

The plan dedicates significant attention to **offshore wind development with 10 GW capacity** split between Gujarat and Tamil Nadu[7][8]. This includes specialized transmission infrastructure:

Gujarat (5 GW Offshore Wind)

- **Mahuva onshore pooling station**: 9×500 MVA, 400/220 kV capacity[5]
- **Ubhrat onshore pooling station**: 4×500 MVA, 400/220 kV capacity[5]
- **Submarine cables**: Multiple 220 kV circuits connecting offshore substations[5]

Tamil Nadu (5 GW Offshore Wind)

- **Avaraikulam onshore pooling station**: 400/220 kV configuration[5]
- **Specialized offshore substations** and submarine cable infrastructure[5]

Inter-regional Transmission Capacity Enhancement

The plan will increase **inter-regional transmission capacity from 112,250 MW to approximately 150,000 MW by 2030**, representing a **34% increase**[1][5]. This enhancement is crucial for:

- Optimal utilization of renewable resources across regions
- Grid stability and reliability
- Efficient power trading between surplus and deficit regions

Financing and Implementation Strategy

The CEA recommends a **multi-pronged financing approach** similar to the Green Energy Corridor schemes[5]:

- **Central Financial Assistance (CFA)** from the government
- **Low-cost financing** from multilateral agencies
- **Private sector participation** through competitive bidding processes
- **Tariff Based Competitive Bidding (TBCB)** for major transmission projects

Regional Development Focus

Northern Region (Rajasthan - 75 GW)

The plan identifies multiple renewable energy zones across Rajasthan districts including Bikaner, Jalore, Sanchore, Sirohi, Pali, Ajmer, Nagaur, Jaisalmer, Jodhpur, and Barmer[5]. Key infrastructure includes:

- **Multiple 765 kV pooling stations** across major RE zones
- **Extensive 400 kV interconnection networks**
- **HVDC terminal stations** for long-distance power evacuation

Southern Region (86 GW across 4 states)

Focuses on Andhra Pradesh, Karnataka, Telangana, and Tamil Nadu with emphasis on:

- **High-capacity pooling stations** (up to 5×1500 MVA)
- **Submarine cable infrastructure** for Tamil Nadu offshore wind
- **Interstate coordination** for power evacuation

Western Region (20.5 GW across 3 states)

Covers Gujarat, Maharashtra, and Madhya Pradesh with:

- **Offshore wind evacuation systems** in Gujarat
- **Flexible AC transmission systems** for grid stability
- **Dynamic compensation requirements** for renewable integration

Technology and Innovation Aspects

The transmission plan incorporates **advanced technologies** to handle high renewable energy penetration[11][12]:

- **Flexible AC Transmission Systems (FACTS)** devices
- **STATCOM and Synchronous Condensers** for reactive power support
- **Dynamic Line Rating** systems for optimized transmission capacity
- **Hybrid substations** and monopole structures for space optimization

Environmental and Social Considerations

The plan addresses **environmental impact mitigation** through:

- **Optimized corridor utilization** to minimize land acquisition
- **Submarine cable routing** to reduce coastal environmental impact
- **Coordination with local communities** for smooth project implementation
- **Wildlife protection measures** in sensitive ecological zones like the Great Indian Bustard habitat

Grid Integration and Stability Measures

To ensure grid stability with high renewable penetration, the plan includes[11][13]:

- **Short Circuit Ratio (SCR) assessments** at various locations
- **Inertia support systems** through synchronous condensers
- **Advanced grid codes** for renewable energy integration.

Conclusion and Strategic Implications

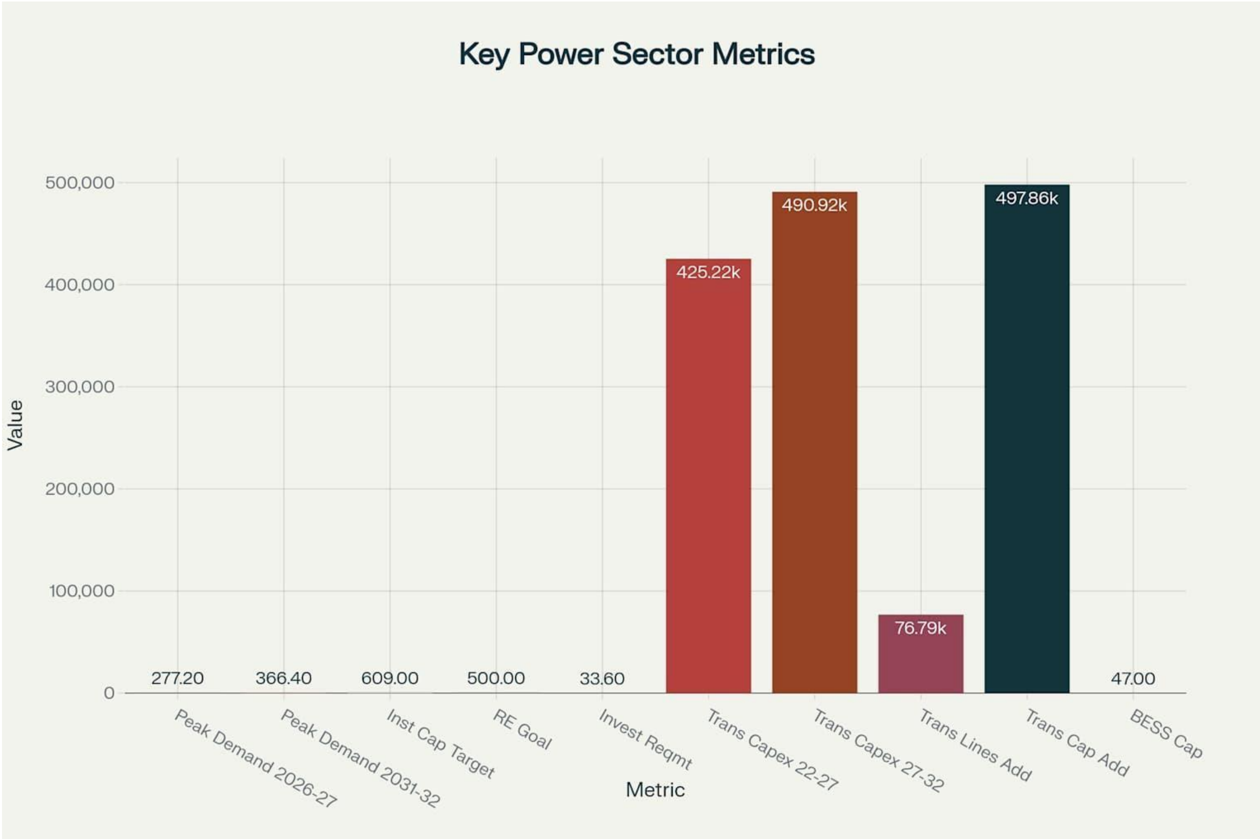
The CEA transmission plan represents a **transformational infrastructure development program** that will enable India to achieve its ambitious renewable energy targets. The comprehensive approach addresses technical, financial, and operational challenges while ensuring grid reliability and optimal resource utilization. The successful implementation of this plan will position India as a global leader in renewable energy integration and contribute significantly to its climate commitments under the Paris Agreement[2][12].

The plan's **phased implementation approach** ensures manageable execution while the **diverse geographical distribution** of renewable energy zones provides grid stability and energy security. The integration of **51.5 GW BESS capacity** addresses intermittency challenges, making the renewable energy system more reliable and dispatchable for round-the-clock power supply.

Section 2:National Electricity Plan & CERC Regulations

Key Data Summary

Metric	Value
Peak Demand Forecast (2026-27)	277.2 GW[1][2][3]
Peak Demand Forecast (2031-32)	366.4 GW[1][2][3]
Installed Capacity Target (2031-32)	609 GW[1][3]
Renewable Energy Goal (by 2030)	500 GW (non-fossil)[1][2][3]
Investment Requirement (2022-32)	₹33.6 trillion[1][3]
Transmission Capex (2022-27)	₹4.25 lakh crore[3]
Transmission Capex (2027-32)	₹4.9 lakh crore[3]
Transmission Lines Addition (2027-32)	76,787 ckm[3]
Transformation Capacity Addition (2027-32)	497,855 MVA[3]
Battery Energy Storage Target (by 2032)	47 GW[3]



Key Data Summary of National Electricity Plan & CERC Regulations

Technical Standards: CEA, CERC, CTU, Grid-India

Ride-Through Capability (LVRT & HVRT)

- **Low Voltage Ride-Through (LVRT) & High Voltage Ride-Through (HVRT):** All generating stations must remain connected to the grid during voltage dips and surges within prescribed limits, ensuring stability during grid disturbances[4][5].
- **Assessment:** Compliance is tested at the Point of Interconnection (POI) for both balanced and unbalanced faults.

Reactive Power Capability

- **Requirement:** Generators must maintain a power factor between 0.95 lagging and 0.95 leading at rated output, supplying dynamically varying reactive power as needed[5][6].
- **Purpose:** Supports voltage stability and grid reliability, especially with high renewable penetration.

Ramp Capability

- **Active Power Ramp Rate:** Generators must control ramp rates to within ±10% of rated output per minute[4][7][8].
- **Minimum Ramp Rate:** 1% per minute is incentivized; failure to achieve this incurs a penalty (0.25% reduction in return on equity), while exceeding it is rewarded (up to 1% additional return)[7].
- **Implementation:** Ramp tests are mandatory for all new RE generators.

Frequency Response and Synthetic Inertia

- **Frequency Droop:** Generators must provide frequency response with a droop of 3–6% and a dead band ≤0.03 Hz[4].
- **Synthetic Inertia:** Stations must deliver a power-frequency response of at least 10% of maximum capacity within 1 second for frequency deviations less than 0.3 Hz[4].

Additional Technical Requirements

- **Harmonic Control:** Harmonic current injection at the POI must not exceed IEEE 519 limits.
- **Flicker and DC Injection:** Flicker and DC current at POI must remain within IEC 61000 and CEAspecified limits[5].
- **Protection Protocol:** Uniform protection protocols, annual audits, and backup protection systems are mandatory for all grid users[9].

Regulatory and Implementation Framework

- **CERC & CEA:** Set, monitor, and enforce technical standards for connectivity, grid operation, and protection[9][10].
- **CTU & Grid-India:** Oversee interconnection studies, system integration, and real-time grid operations[9][7].
- **Grid Modernization:** Communication, data exchange, and real-time monitoring systems are prioritized for efficient grid management[9][10].

This concise overview combines the essential data, technical standards, and regulatory framework shaping India's power sector transformation under the National Electricity Plan and CERC regulations.

Section 3:Green Energy Corridors & OSOWOG

Executive Summary

India's **Green Energy Corridors (GEC)** and **One Sun One World One Grid (OSOWOG)** initiatives represent critical infrastructure programs for renewable energy integration and international grid connectivity. The combined investment across these programs exceeds **Rs 10 lakh crore**, aimed at evacuating over **500 GW of renewable energy** and establishing **global grid interconnections** by 2030-2032[1][2].

Green Energy Corridors: Phase-wise Development

Current Status and Investment Framework

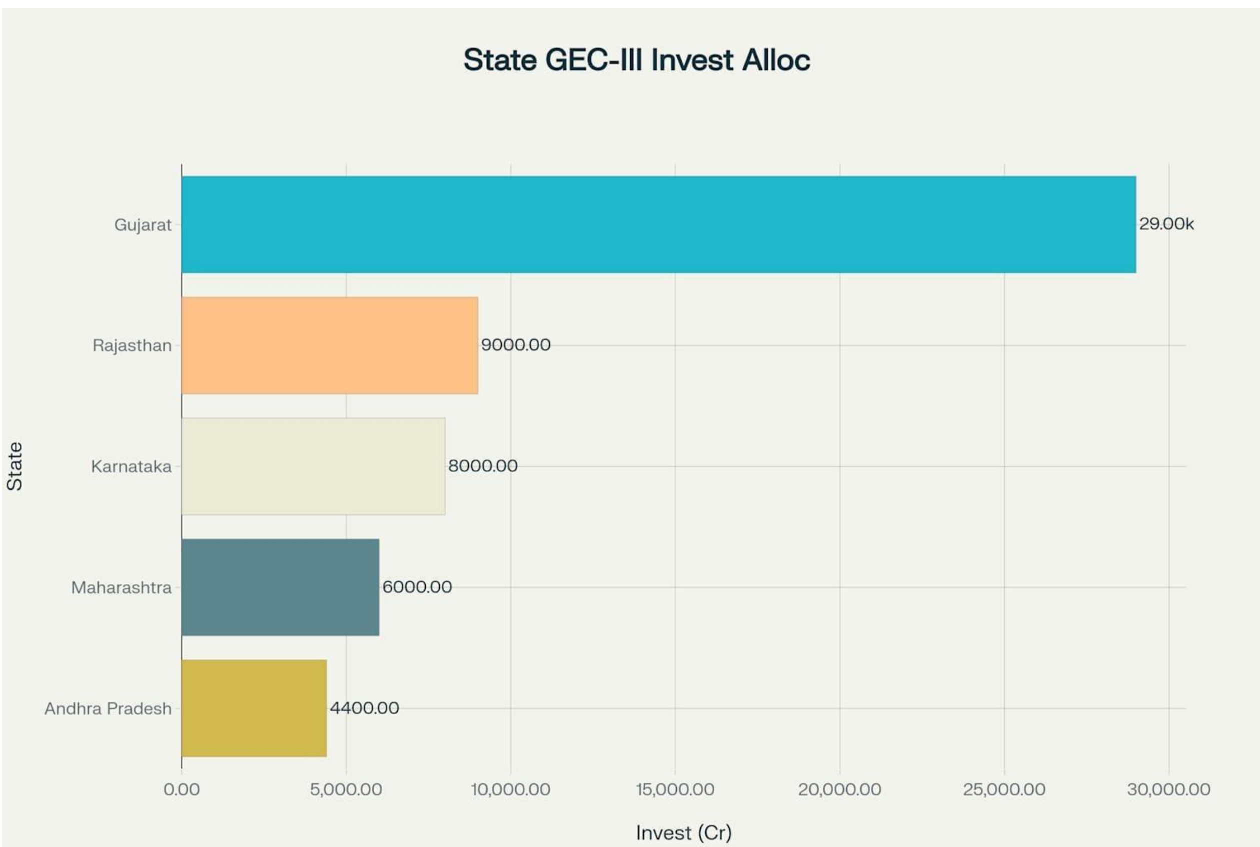
The Green Energy Corridor project spans three phases with a total investment of **Rs 79,400 crore** across **47,686 circuit kilometers** of transmission lines[1][3]. The program targets evacuation of **144 GW renewable energy capacity** through dedicated transmission infrastructure[4][5].

Comprehensive visualization of Green Energy Corridors phases, state-wise investments, cross-border capacity, and CTUIL transmission plans

GEC Phase-I has been largely completed with **9,136 circuit kilometers** of transmission lines and **21,413 MVA** of substations commissioned across eight states[1][4]. The phase targeted **24 GW renewable energy evacuation** with an investment of **Rs 11,369 crore**[4].

GEC Phase-II is under implementation across seven states with **7,919 circuit kilometers** and **24,488 MVA** substations planned for completion by **FY26**[4][6]. The phase has an approved outlay of **Rs 12,031 crore** for **20 GW renewable energy capacity**[4].

GEC Phase-III is entering the planning phase with an estimated cost of **Rs 56,000 crore** and **40% central government funding**[5][7]. The phase will focus on **high-voltage direct current (HVDC) transmission lines** and is proposed for announcement in **Budget 2025**[8][6].



State-wise investment allocation for Green Energy Corridor Phase-III across five major states

State-wise Implementation

Gujarat leads GEC-III investment with **Rs 29,000 crore** allocation, followed by **Rajasthan** (Rs 9,000 crore), **Karnataka** (Rs 8,000 crore), **Maharashtra** (Rs 6,000 crore), and **Andhra Pradesh** (Rs 4,400 crore)[5][7].

Gujarat's investment will enable transmission of **16,500 MW renewable power** through **3,430 circuit kilometers** of 765 kV lines and **860 circuit kilometers** of 400 kV lines[5].

OSOWOG Initiative: Global Grid Integration

Three-Phase Implementation Strategy

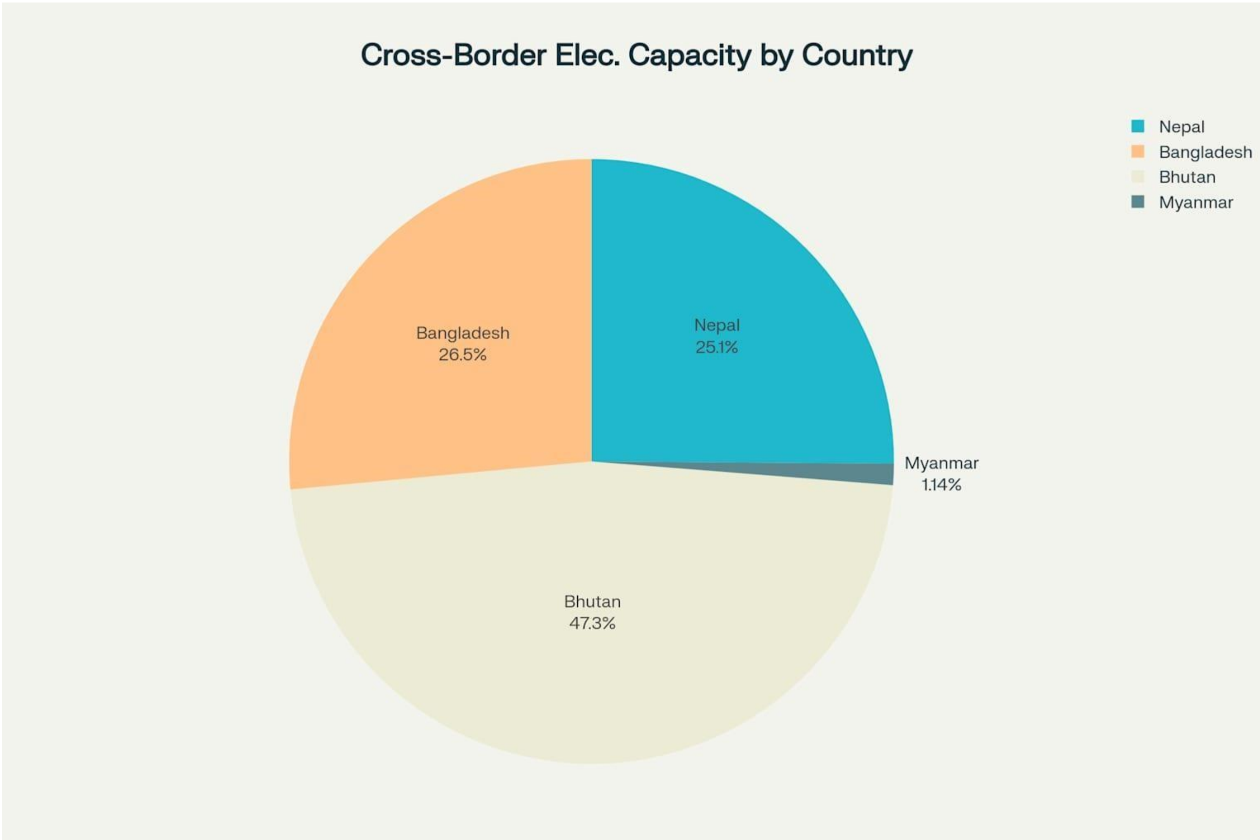
The OSOWOG initiative follows a **three-phase approach** targeting **140 countries** with **2,600 GW interconnection capacity** by 2050[9][10][11]. The initiative is supported by **India, UK, International Solar Alliance (ISA), and World Bank Group**[10][12].

Phase I (2025-2030) focuses on connecting **South Asia, Middle East, and Southeast Asia** with **50 GW interconnection capacity**[11][13]. This phase leverages existing cross-border infrastructure and planned projects like the **India-Oman undersea cable**[14][15].

Phase II (2030-2035) extends the Asian grid to **Africa** with **150 GW capacity**, while **Phase III (2035-2050)** achieves **global interconnection** with **2,600 GW capacity**[11][16].

Cross-Border Infrastructure Development

India currently exchanges **4,100 MW** with neighboring countries through established transmission links[17][14]. This capacity is projected to increase to **7,000 MW by 2026-27** with new interconnections under development[17][18].



Current cross-border electricity exchange capacity distribution across neighboring countries

Key existing cross-border connections include:

- **Nepal**: 1,100 MW through Dhalkebar-Muzaffarpur 400 kV line[17][19]
- **Bangladesh**: 1,160 MW via Baharampur-Bheramara 400 kV connection[17]
- **Bhutan**: 2,070 MW from multiple hydroelectric projects[17]
- **Myanmar**: 50 MW through Moreh-Tamu 230 kV line[17]

Planned International Projects

Major cross-border projects under OSOWOG include:

- **India-Sri Lanka HVDC**: 1,000 MW capacity over 285 km with **Rs 3,000 crore investment**[17]
- **India-Oman Undersea Cable**: 3,000 MW capacity over 1,000 km with **Rs 40,000 crore investment**[14][15]
- **India-UAE Grid**: 2,000 MW capacity under discussion[14]
- **India-Saudi Arabia Grid**: 2,000 MW undersea connection being finalized[14][15]

CTUIL Transmission Infrastructure Plan

National Electricity Plan Implementation

The Central Transmission Utility of India Limited (CTUIL) has outlined a **Rs 9.16 lakh crore investment plan** for transmission infrastructure development between **2022-2032**[20][18]. The plan includes **1,91,474 circuit kilometers** of transmission lines and **1,274 GVA transformation capacity**[20][21].

CTUIL transmission infrastructure investment plan showing period-wise allocation from 2022-2032

The investment is phased as:

- **2022-27**: Rs 4.25 lakh crore for **114,687 ckm** transmission lines
- **2027-32**: Rs 4.91 lakh crore for **76,787 ckm** transmission lines
- **Total HVDC capacity**: 33.25 GW bipole links planned[20][21]

Inter-regional Capacity Enhancement

Inter-regional transmission capacity will increase from **119 GW** currently to **143 GW by 2026-27** and **168 GW by 2031-32**[20][21]. This enhancement supports optimal renewable energy utilization across regions and improved grid stability[18][22].

Technology Integration and Innovation

Advanced Transmission Technologies

The corridors incorporate **HVDC transmission systems** for long-distance renewable energy evacuation, **undersea cables** for international connections, and **smart grid technologies** for real-time monitoring[23][24]. **Battery Energy Storage Systems (BESS)** of **47-51.5 GW capacity** are planned to address renewable energy intermittency[2][22].

Grid Modernization Features

Advanced features include:

- **Flexible AC Transmission Systems (FACTS)** for grid stability
- **STATCOM and Synchronous Condensers** for reactive power support
- **Dynamic Line Rating** systems for optimized transmission capacity
- **Real-time monitoring** and control infrastructure[2]

Economic and Strategic Impact

Investment and Financing Framework

The combined GEC and OSOWOG programs require **multi-source financing** including central government assistance, multilateral agency funding, and private sector participation[2][5]. The **40% central funding** for GECIII demonstrates government commitment to renewable energy infrastructure[5][7].

Regional Energy Security

These initiatives enhance **energy security** through diversified power sources, **economic cooperation** through energy trade, and **grid resilience** against disruptions[17][23]. The programs support India's **500 GW non-fossil fuel capacity target by 2030**[25][7].

Implementation Challenges and Solutions

Technical and Regulatory Aspects

Key challenges include **right-of-way acquisition**, **environmental clearances**, and **cross-border regulatory harmonization**[18]. Solutions involve **streamlined approval processes**, **advanced technologies** for space optimization, and **international cooperation frameworks**[23][24].

Timeline and Completion Status

GEC-I completion varies by state with **Rajasthan, Tamil Nadu, Karnataka, and Madhya Pradesh** completed, while **Andhra Pradesh, Himachal Pradesh, Maharashtra, and Gujarat** have extensions until **2025**[1][4]. **GEC-II** targets **FY26 completion**, and **GEC-III** planning phase begins with **March 2025 deadline** for state proposals[4][6].

The integrated approach of Green Energy Corridors and OSOWOG positions India as a **global leader in renewable energy infrastructure** and **international grid connectivity**, supporting both domestic energy security and global climate commitments.

2.Current Status & Gap Analysis

□ Installed Capacities

1. As of Feb 2025: ~223 GW Non-Fossil, ~215 GW Renewables; ~24 GW added YTD
□ Non-Fossil Fuel Capacity (~223 GW) This includes:
Renewables (Solar, Wind, Biomass, Small Hydro) = ~215 GW
Large Hydro & Nuclear = ~8 GW
Non-fossil capacity refers to energy sources not based on fossil fuels like coal or gas.

□ Renewable Energy Capacity (~215 GW) Breakdown (approximate):
Solar Power: ~85 GW
Wind Power: ~48 GW
Others (biomass, small hydro, waste-to-energy): ~82 GW
Renewables are clean, sustainable, and essential for India's climate commitments.

□ YTD Addition (~24 GW)
"YTD" = Year-To-Date – means the amount added from April 2024 to February 2025. This reflects strong project commissioning pace, aided by government support and private investments.

ALL INDIA INSTALLED CAPACITY (IN MW) OF POWER STATIONS
(As on 31.05.2025)
(UTILITIES)

Region	Ownership/ Sector	Mode wise breakup									Grand Total
		Thermal					Nuclear	Renewable			
		Coal	Lignite	Gas	Diesel	Total		Hydro	RES*(MNRE)	Total	
Northern Region	State	20845.00	250.00	2703.90	0.00	23798.90	0.00	6108.24	818.00	6926.24	30725.14
	Private	22084.33	1080.00	664.00	0.00	23828.33	0.00	3241.00	47210.87	50451.87	74280.20
	Central	16368.62	250.00	2344.06	0.00	18962.68	2220.00	12241.51	379.00	12620.51	33803.19
	Sub Total	**59297.95**	**1580.00**	**5711.96**	**0.00**	**66589.91**	**2220.00**	**21590.75**	**48407.87**	**69998.62**	**138808.53**
Western Region	State	21120.00	900.00	2693.72	0.00	24713.72	0.00	5446.50	619.23	6065.73	30779.45
	Private	30217.17	500.00	3425.00	0.00	34142.17	0.00	481.00	63832.01	64313.01	98455.18
	Central	21610.47	0.00	3280.67	0.00	24891.14	3240.00	1676.00	666.30	2342.30	30473.44
	Sub Total	**72947.64**	**1400.00**	**9399.39**	**0.00**	**83747.03**	**3240.00**	**7603.50**	**65117.54**	**72721.04**	**159708.07**
Southern Region	State	22992.50	0.00	1162.03	159.96	24314.49	0.00	11927.48	637.08	12564.56	36879.05
	Private	13636.00	250.00	1834.50	273.70	15994.21	0.00	0.00	60935.20	60935.20	76929.41
	Central	13827.04	3390.00	359.58	0.00	17576.62	3320.00	0.00	541.90	541.90	21438.52
	Sub Total	**50455.54**	**3640.00**	**3356.11**	**433.66**	**57885.31**	**3320.00**	**11927.48**	**62114.18**	**74041.66**	**135246.97**
Eastern Region	State	6970.00	0.00	0.00	0.00	6970.00	0.00	3550.22	278.11	3828.33	10798.33
	Private	5723.00	0.00	0.00	0.00	5723.00	0.00	209.00	2190.45	2399.45	8122.45
	Central	16081.86	0.00	0.00	0.00	16081.86	0.00	1103.20	10.00	1113.20	17195.06
	Sub Total	**28774.86**	**0.00**	**0.00**	**0.00**	**28774.86**	**0.00**	**4862.42**	**2478.56**	**7340.98**	**36115.84**
North Eastern Region	State	0.00	0.00	411.36	36.00	447.36	0.00	422.00	276.25	698.25	1145.61
	Private	0.00	0.00	0.00	0.00	0.00	0.00	0.00	357.36	357.36	357.36
	Central	1242.02	0.00	1253.60	0.00	2495.62	0.00	1522.01	30.00	1552.01	4047.63
	Sub Total	**1242.02**	**0.00**	**1664.96**	**36.00**	**2942.98**	**0.00**	**1944.01**	**663.61**	**2607.62**	**5550.60**
Islands	State	0.00	0.00	0.00	84.35	84.35	0.00	0.00	5.25	5.25	89.60
	Private	0.00	0.00	0.00	35.19	35.19	0.00	0.00	30.49	30.49	65.68
	Central	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.10	5.10	5.10
	Sub Total	**0.00**	**0.00**	**0.00**	**119.54**	**119.54**	**0.00**	**0.00**	**40.84**	**40.84**	**160.38**
ALL INDIA	State	71927.50	1150.00	6971.01	280.31	80328.82	0.00	27454.44	2633.92	30088.36	110417.18
	Private	71660.50	1830.00	5923.50	308.89	79722.90	0.00	3931.00	174556.38	178487.38	258210.28
	Central	69130.00	3640.00	7237.91	0.00	80007.91	8780.00	16542.72	1632.30	18175.02	106962.93
	Total	**212718.00**	**6620.00**	**20132.42**	**589.20**	**240059.62**	**8780.00**	**47928.16**	**178822.60**	**226750.76**	**475590.38**

Figures at decimal may not tally due to rounding off

2. By May 2025: ~232 GW Total Renewables → Halfway to 500 GW India's
2030 target is 500 GW of non-fossil capacity.
At 232 GW, India is at ~46% progress — halfway there.
The rate of addition must increase further to meet the goal in the next 5 years.

Infrastructure Shortfalls

A. Transmission Expansion Lagging (Green Corridors)

What is Transmission Infrastructure?
It's the network of high-voltage lines that transport electricity from power plants (e.g., solar farms) to homes, industries, and cities.

What are Green Energy Corridors (GEC)?
A project initiated to Build dedicated lines for renewable power evacuation.

Ensure grid stability and reduce curtailment (unused RE due to transmission limits).

? Current Issues:
Delays in GEC-II, land acquisition, clearances.
Congestion in RE-rich states like Rajasthan, Gujarat, Tamil Nadu.
Inadequate grid balancing tools for variable solar/wind. ?
Impact:
Even if RE is generated, it can't be delivered reliably to the grid, leading to loss of clean energy and financial losses for developers.

B. Storage Limited (~4.7 GW PHS, 0.22 GWh BESS vs. 60 GW+ Needed) ?
Why is Storage Needed?
Renewable sources like solar and wind are intermittent (daytime only / seasonal). Storage helps:

Store excess power when generation is high.
Release it during peak demand or low RE output.

? Pumped Hydro Storage (PHS) – 4.7 GW Oldest form of grid storage.
Works by pumping water to a height and releasing it to generate power.
India has limited new sites and long approval times.

? Battery Energy Storage Systems (BESS) – 0.22 GWh Newer, fast-responding storage (like large lithium-ion batteries).
Mostly small-scale pilots in India as of 2025.

? Required by 2030: 60 GW+ Storage
As per CEA & NITI Aayog, this is the minimum required to handle 500 GW RE. Need large investments, stable policy support, and viable business models.

C. Regulatory Bottlenecks

1. Slow PPAs (Power Purchase Agreements) ?
What is a PPA?

A long-term contract between a renewable power generator and a buyer (e.g., distribution utility or DISCOM), stating:
How much electricity will be bought.
At what tariff.
For how long (usually 25 years).

? Current Issues:

Delays in signing PPAs after auctions.
Buyers (DISCOMs) reluctant due to:
Overcapacity fears.
Low demand growth.
Push for lower tariffs than previously agreed.

Impact:
Projects get delayed or abandoned.
Developers face financial uncertainty.
2. Interstate Transmission Delays

What is ISTS (Interstate Transmission System)?
Allows power flow between states via national transmission grid.
Key for moving RE from generation zones (e.g., Rajasthan) to consumption centers (e.g., Delhi, Maharashtra).

Challenges:
ROW (Right of Way) issues.
Forest/environmental clearances delays.
Complex coordination between states and central agencies.

3. Tender Cancellations (>38 GW) What is a Tender?
Government or agency invites bids for RE project development.
After bidding, winners get allocation and start building.

Problems in 2023–2025:
Over 38 GW of tenders cancelled or put on hold.
Reasons:
Tariff renegotiation by states.
Policy reversals.
Land or grid unavailability.

Impact:
Loss of investor confidence.
Stalled progress toward 2030 goals.

3.Technical Challenges in Integrating 500 GW Renewable Energy

1. Grid Stability & Flexibility

- Problem: Solar and wind are intermittent sources. Their output is not constant, leading to supplyfluctuations.

- Why it matters: These fluctuations cause voltage and frequency instability, risking blackouts.

- Solutions:

- Battery Energy Storage Systems (BESS)

- Flexible hydro and thermal plants

- Demand response mechanisms to balance load in real-time

2. Transmission Capacity & Planning

- Problem: RE is generated in remote areas but consumed in urban zones. Long-distancetransmission is needed.

- Requirement:

- 8,120 ckm HVDC

- 26,000 ckm 765 kV lines

- 16,000 ckm 400 kV and 1,000 ckm 220 kV

- Challenge: Delays due to land acquisition, cost, and inter-agency coordination.

3. Evacuation of Power from Renewable Parks

- Example: Bhadla and Khavda parks generate thousands of MW.

- Problem: Need for dedicated high-capacity corridors.

- Additional Challenge: Requires central and state coordination, land management, and funding.

4. Policy and Market Dynamics (Technical Side)

- Financing Issues: High capital cost for storage and grid infrastructure.

- PPA Delays: Developers hesitate without long-term contracts.

- Weak RPO Enforcement: States not complying affects planning and RE investments.

CASE STUDIES

- **Bhadla Solar Park(2245 MW)**
- **Khavda Hybrid Renewable Park(30 GW)**
- **OSOWOG/global grid learning**

Solar Power in India:
A Case Study of the Bhadla Solar Power Park

CFA
Centre for Financial Accountability

Solar Power in India:

Case Study of the Bhadla Solar Power Park

Introduction

The Bhadla Solar Power Park, boasting a capacity to generate 2245 MWs of solar power, stands as the world's largest solar power park. Spanning across a vast expanse of 5700 hectares, a size almost equivalent to that of San Marino[1]. Bhadla has been touted as a striking exemplar of how a fusion of innovation, cutting-edge technology, and a blend of public and private financial support can propel the cause of green energy.

Currently, India accommodates several ultra-mega solar parks boasting capacities exceeding 1GW, two of which stand as the world's largest commissioned parks to date. These solar parks in India consistently draw global investments and interest from esteemed domestic and international renewable energy developers[2].

A Critical look into the Case of Bhadla Solar Power Park

On September 11th, 2023, the state of Rajasthan introduced the preliminary draft of the 2050 Rajasthan Energy Policy[3] , unveiling an ambitious vision for the state's energy landscape. At present, approximately 70% of the state's energy consumption relies on fossil fuels, with renewable energy

1 Verma. (2023, March 17). How PM Narendra Modi is Leading the Way for Green Growth in India. News18. Retrieved October 9, 2023, from https://www.news18.com/opinion/opinion-how-pm-narendra-modi-is-leading-the-way-for-green-growth-in-india-7316845.html

2 Shah. (2020, May). India’s Utility-Scale Solar Parks a Global Success Story: India Is Home to the World’s Largest Utility-Scale Solar Installations. Institute for Energy Economics and Financial Analysis. https://ieefa.org/wp-content/uploads/2020/05/Indias-Utility-Scale-Solar-Parks-Success-Story_May-2020.pdf

3 Hazarika. (2023). Rajasthan Aims to install 90 GW of renewable Energy Capacity by 2030. Mercom Clean Energy Insights. Retrieved December 13, 2023, from https://www.mercomindia.com/rajasthan-aims-to-energy-capacity-by-2030

accounting for just 20%. However, a significant transformation is anticipated by 2050 [4]. The state aims to reverse this energy

[4] See, Heena Moiwala. (2023, September 11).Rajasthan aims for a revolution: targeting 70% green energy by 2050 Udaipurtimes Website. https://udaipurtimes.com/news/rajasthan-energy-policy-2050/cid12159686.htm

consumption pattern, targeting renewable energy sources to constitute 70%, while fossil fuels are projected to make up a mere 20%.

. According to a report by the MNRE, Rajasthan boasts the nation's most substantial installed solar capacity, totaling 7,737.95 Megawatts [5] .However, the development of solar installations and future expansion plans is occurring at the expense of existing village commons, and local floral and faunal resources. Presently Rajasthan houses the largest solar power park in the world, in the Jodhpur district of Rajasthan, in the village Bhadla.

The Bhadla Solar Power Park: An overview

Location:

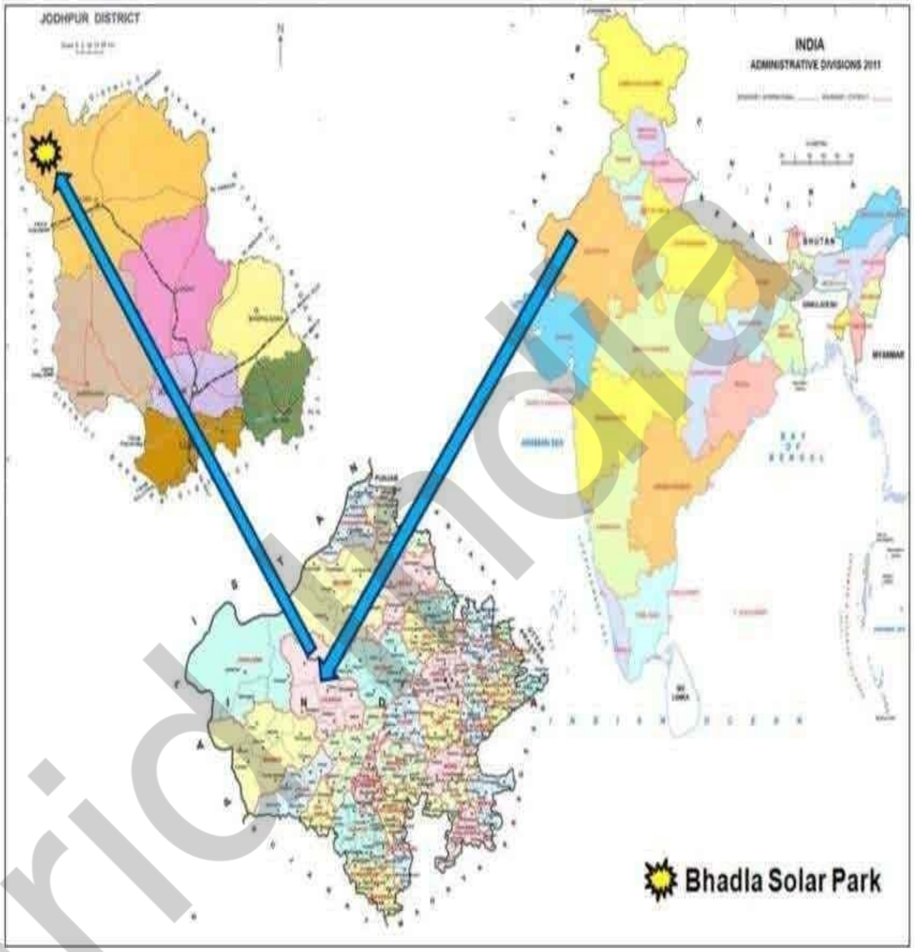
Millions of glistening panels sprawl across an expansive 5,783 hectares in the Bhadla village, in Phalodi tehsil, Jodhpur district. It is situated 220 kilometers away from Jodhpur on the Bap-Bhadla Road. The nearest important town to Bhadla is tehsil headquarters Phalodi at a distance of 83 km.

[5] Saini. (2021, September 23). 'Rajasthan leads solar installed capacity in India': Govt report. Hindustan Times . Retrieved December 13, 2023, from https://www.hindustantimes.com/cities/jaipur-news/rajasthan-leads-solar-installed-capacity-in-india-govt-report-101632399358078.html [46] Rajasthan receives approximately 5.72 kWh/meter square/day of solar radiation.

A location of the Bhadla Solar Power Park in the map is provided below.

Location of the Bhadla Solar Power Park.
Source of Image: India: Rajasthan Renewable Energy Transmission Investment Program: Project 1

Initially, in India's solar power landscape, the Pavagada Solar Park held the title of the world's largest park with a capacity of 2,050 MW. However, in 2020, Bhadla surpassed it to claim the top spot, generating solar energy of 2245 MW.



Nasa Earth Observatory Image of Bhadla Solar Park. Source: [Nasa earth observatory]

Bhadla Solar Power Park. Source: [NS Energy]

The Local Geography of Bhadla Geophysical Particularities:

In Bhadla, desert sands bake in the tropical sun, where the temperature varies in between 46 degree celsius to 48 degree celsius. Bhadla is a region located in the arid landscapes of Rajasthan, India. The primary peculiarity of Bhadla is its abundant sunshine and extreme aridity. This region receives an exceptionally high amount of solar radiation throughout the year, making it an ideal location for solar energy generation. The intense sunlight, with an annual solar insolation exceeding 5.5 kWh/m², has made Bhadla a prominent hub for solar power projects and installations.

Impacts of Transmission lines

According to the report, "India: Solar Transmission Sector Project", Asian Development Bank, under the ADB loan No. 3521-IND, is assisting in the funding of the transmission system of the solar power park at Bhadla. ADB selected this project to be implemented and monitored in line with the POWERGRID's Environmental and Social Policy Procedures (ESPP) and Action plan prepared for the use of the Country Safeguards System, to ensure that ESPP achieves and maintains full equivalence with ADB's Safeguard Policy Statement, 2009.

To facilitate the pooling of power from various Solar Power Modules, and evacuate and transferring of power, a pooling substation of 765/400/220 kV has been

proposed at Bhadla, along with 765 kV interconnection to Bikaner substation[75]. This has been further supplemented with 220kv and 400kv interconnection lines to the 765/400/220 kV substation[6].

Conclusion

In the face of the looming climate crisis, the global response has set in motion an extensive series of structural and infrastructural changes. These initiatives have been driven by the imperative to shift away from fossil fuels towards renewable energy sources. One notable outcome of this endeavor has been the proliferation of large-scale solar infrastructure projects across India, and other places. These projects have been facilitated and funded by international financial institutions such as the World Bank, IFC, the Asian Development Bank, AIIB, and other multilateral financial institutions.

However, the development of solar parks on previously underutilised rural lands has not unfolded without consequences. As their livelihood options dwindle, many are left with little choice but to migrate to urban areas in search of

[5] See page number 6, India: Solar Transmission Sector Project.

employment opportunities, where they become all the more vulnerable to the direct and indirect effects of climate change[6].

[6] See, Chaudhry. (2023, October 14). Climate change and health of the urban poor: The role of environmental justice. The Journal of Climate Change and Health . https://www.sciencedirect.com/science/article/pii/S2667278223000767?via%3Dihub

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Website: www.cenfa.org Email: info@cenfa.org

December 2023

04

Khavda: World's Largest Renewable Energy Project

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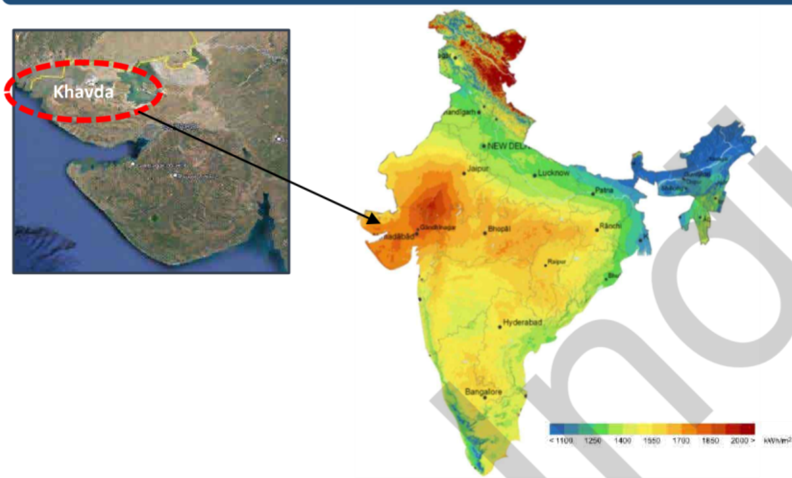
Renewables

Khavda – World's largest single-location Renewable Energy Project

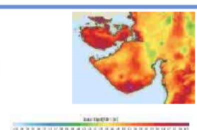
Strategically located in Resource rich region of Gujarat



Arid, non-cultivable contiguous land perfectly suited for mega scale RE development

Solar irradiation of ~2,060 kWh/ m^2

Wind speed of ~8 meters/ second



A Renewable Energy Marvel in the Making

Significant Scale Efficiencies	✓ All projects to be developed on contiguous land in Khavda Renewable Park ✓ Significant scale efficiencies in construction & O&M
Well Planned Evacuation	✓ Advance phase wise evacuation planning matching AGEL's project timelines ✓ Connection to central grid and existing green corridor through high capacity transmission lines including 765 kV
Advance Design planning **Customized to the terrain** **Backed by extensive studies**	✓ Topography survey ✓ Geotechnical Investigation for Soil ✓ Seismic Study ✓ Centrifuge Study ✓ Soil improvement Tests for WTG foundation ✓ Corrosion Study on Steel Structure & Concrete ✓ Area Drainage Study ✓ Customized design planning for Cable laying, piling, extra high voltage (EHV) substation and more

First project of 551 MW operationalized in Feb 2024

30 GW

Spread across 530+ sq. km – 5x of Paris

Note: All capacities in MW_{AC}
CUF – Capacity Utilization Factor; SECI – Solar Energy Corporation Limited; Wp – Watt Peak; HSAT – Horizontal Single Axis Tracking System;

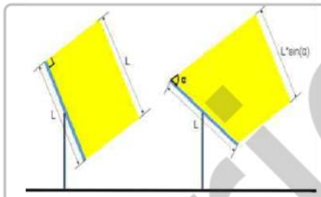
Khavda – Latest technology adoption to optimize the LCOE

adani Renewables

TOPCon, N-type, Bifacial modules

- ✓ 580+ Watt peak modules
- ✓ Higher overall efficiency
- ✓ Better low light performance
- ✓ Lower degradation
- ✓ Longer life expectancy
- ✓ Bifacial - Solar power generation from both sides of the panel

Horizontal Single-Axis Tracking system



- ✓ Tracks the sun throughout the day
- ✓ Modules are fixed on the mounted Structure & will be rotated around a horizontal axis

Solar CUF of ~ 33%

5.2 MW Wind Turbines – India's highest rated capacity

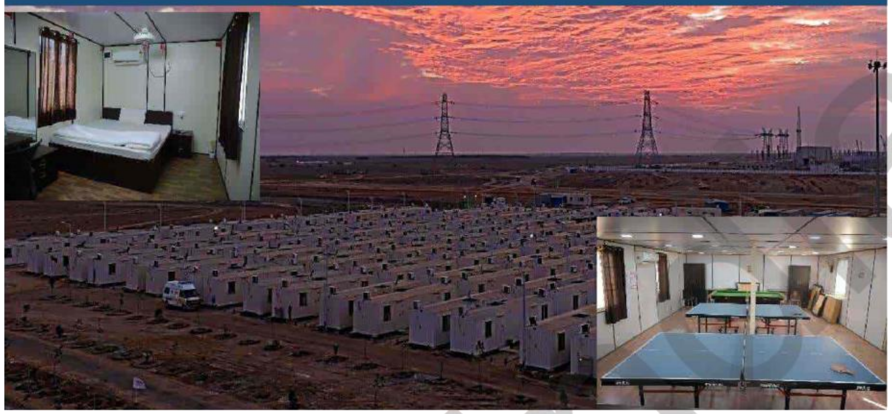
- ✓ Developed indigenously by Adani New Industries Ltd in partnership with W2E, Germany
- ✓ Rotor diameter of 160 meters
- ✓ Tip height of 200 meters
- ✓ Included in MNRE's Revised List of Models and Manufacturers (RLMM)
- ✓ Accredited with Certificate under IEC System from WindGuard GmbH aligning with the highest global quality and safety standards

Wind CUF of ~ 38%

Advanced technology adoption leading to higher electricity generation

Khavda – Complete Project & Social Ecosystem in place

Township for the workforce



- ✓ Operationalized **Airstrip and approach roads** for transfer of materials and resources
- ✓ **Employee Residential Camp** with canteen in place and being expanded
- ✓ **Workers Camp** with canteen in place and being expanded
- ✓ **O&M Township** under construction
- ✓ Operationalized **Healthcare facility with Ambulance, Fire tender, Recreational facilities, RO Water Plant, Sewage treatment plant and more.**

Construction Control Room

Site Office

Cable pullers for HT Cable

Shopping Complex

Airstrip

Healthcare Facility

RO Water Plant

Warehouses for materials

Khavda – ESG Implementation

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Standardized ESG Practices

Study/Assessment	Consultant
☑ Environment & Social Impact Assessment (ESIA)	ARCADIS
☑ Critical Habitat Assessment (CHA)	
☑ Climate Change Risk Assessment (CCRA)	
☑ Human Rights Risk Assessment (HRRA)	
☑ Environment & Social Due Diligence (ESDD)	AECOM
☑ E&S action plan (ESAP) monitoring	
☑ Bird & Bat monitoring	

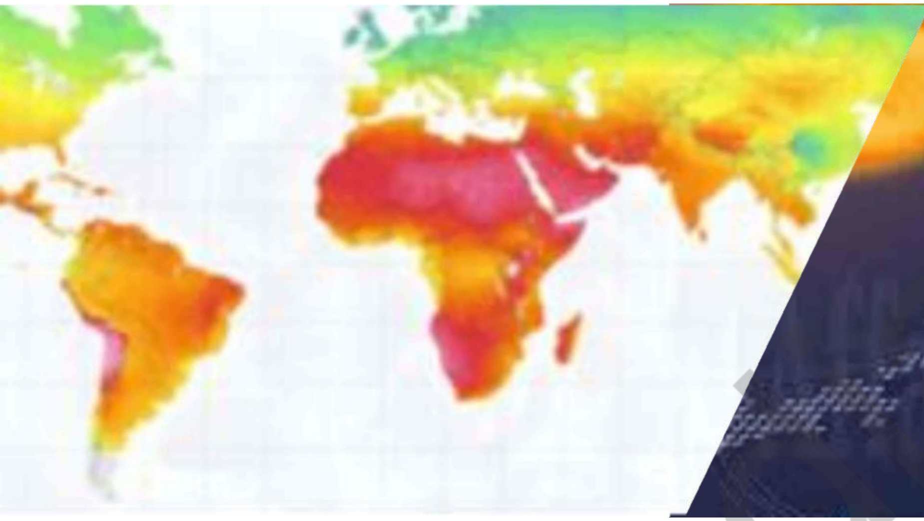
- ✓ Developed an entire **social ecosystem for the employees** and contractual workers
- ✓ **Waterless robotic cleaning** to address dust accumulation on solar panels, contributing to the UNSDG 6 by conserving water in the arid Kutch region and maximize electricity generation
- ✓ **Developing indigenous resilient supply chain** with significantly increased share of localized procurement, such as WTGs and trackers.

Contributing to a greener planet with 30 GW RE plant

- **~81 Billion units** of RE electricity generation
- To power **16.1 Million households**
- **15,200+** Green Job Creation
- CO_2 avoidance of **58 million Tons**
- Avoidance of **~60,300 tonnes of coal**
- CO_2 emission avoidance equivalent to carbon sequestration by **2.8 Bn trees**

Empowering tomorrow with clean energy today

UNSDG: United Nations Sustainable Development Goal



01 One Sun One World One Grid' (OSOWOG)-A Grand Vision

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IRADe Integrated Research and Action for Development

01 One Sun One World One Grid-A Grand Vision:- Concept

Renewable Energy (RE) grid parity across countries

RE Cost decline 2010-19
Solar PV 82%, CSP-47%
Onshore-40%
Offshore wind 29%
India-Lowest Solar Tariffs- 1.99 Rs/Kwh (US cent 2.7/Kwh)

Source : IRENA

Has triggered accelerated large-scale RE deployment, worldwide

2537 GW of RE-2019-
1227 GW of RE-2010

Source : IRENA

RE can help in Economical Energy Transition

Provided its distributed nature, intermittency and demand supply mismatch are addressed in a timely, geographically coordinated and an effective manner

A larger grid based interconnectivity across geographies has the potential to overcome these challenges

Enabling the world to transition to clean energy in a sustainable manner

Global Package for Addressing Energy Affordability, Accessibility and Sustainability

In one hour, the Earth's atmosphere receives enough sunlight to power the electricity needs of every human being on Earth for a year Source : NG

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01 One Sun One World One Grid(OSOWOG)-Grand Vision & Concept

Idea Announced in October 2018

The "**Sun Never Sets**", globally, at any given point of time.

Building a **global ecosystem of interconnected RE**, seamlessly shared for **mutual benefits & global sustainability**

With India at the fulcrum, the solar spectrum can easily be divided into two broad zones viz. **far East** etc. and **far West**

Far East include countries like Myanmar, Vietnam, Thailand, Lao, Cambodia etc. and far West which would cover the Middle East and the Africa Region. Source : RFP OSOWOG

Matching the demand and supply centre across geographies

Interconnectors as a mean/solution to manage intermittencies

Reduce Curtailment, Exploiting the time zone difference.

Grid safety and security

Economies of Scale

Resulting economic benefits would positively impact

Attracting investments

Poverty alleviation

Reduced project costs

Support in mitigating water, sanitation, food and

Higher efficiencies and increased asset utilization

Other socioeconomic challenges.

Source : Based on RFP OSOWOG

OSOWOG- Potential for Regional & Trans-Region Transmission Interconnection, Interconnectors among countries

While plan is grand, we have various proven regional grid interconnection exist around the globe such as Europe etc. backed with HVDC technologies

03.4 One Sun One World One Grid (OSOWOG)-Progress So far

Hon'ble Prime Minister of India, Shri Narendra Modi, Announced One Sun One World One Grid, First assembly of International Solar Alliance

(October 2018)

COP-24

Theme of India Pavilion

One World One Sun One Grid

(Dec, 2018)

सत्यमेव जयते
Ministry of New and Renewable Energy
Government of India

MNRE–OSOWOG-RFP Developing a long-term vision, implementation plan, roadmap, institutional framework for Implementing OSOWOG

(May 2020)

ISA First World Solar Technology Summit, MoU- signed among the ISA, the Government of India and the World Bank. ***(ISA to act as Nodal Agency)***

(Sept, 2020)

The first plenary on OSOWOG

Side-lines of the Third Assembly of ISA-Member countries

(October 2020)

eDF
Aets apave
teri THE ENERGY AND RESOURCES INSTITUTE

Consortium Awarded the work -Developing a long-term vision, implementation plan, road map, institutional framework for Implementing OSOWOG

(January,2021)

Expected to be released in next Conference of the Parties (COP 26)

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03.5 Study "Developing a Long-term vision, Implementation Plan, Road Map and Institutional Framework for Implementing "One Sun One World One Grid"

Phase I Assessment stage

- Demand supply scenario till 2050.
- Renewable energy resource potential assessment (including decentralized sources).
- Power market assessment.
- Comprehensive vision & road map for OSOWOG.

Phase II: Potential assessment and pilots identification

- Identify 2-3 cross-border projects (that can be initiated within 1 or 2 years)
- Preferably one with each of Middle East, South East and Africa regions considering India as the grid fulcrum.
- Detailed policy and regulatory scan of the identified countries, to identify readiness

Phase III: Full scale roll out

- Develop institutional framework for international co-operation, steering arrangements and governance
- Support in developing an implementation roadmap
- Includes the establishment of a framework for Project Management Office (PMO) as per MNRE's requirement

isa INTERNATIONAL SOLAR ALLIANCE

The International Solar Alliance (ISA) Acts as a Nodal Agency for all activities including implementation of the OSOWOG study for developing a long-term vision, implementation plan, road map and institutional framework for implementing the initiative.

Source : Based on RFP OSOWOG dated May 2020 and first corrigendum dated 28th Sep. 2020 Source : Based on INTERNATIONAL SOLAR ALLIANCE Background Note

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04 One Sun One World One Grid- Way Forward

Building Regional, Sub-Regional, Continental and Global Consensus on Interconnections

Navigating Centralised ~ Decentralised Approach~ Combination

Deepening International Energy Cooperation and Navigating Geopolitical realities

Feasible & Credible Inter-Regional/Continental Pilots, Further Optimisation of cost of Transmission

Navigating Economies of Scale ~ Economies of Large Numbers

Policy, Regulatory and market harmonization, Mobilising Investment & Finance, World Solar Bank

Non Engineering Cost

(Right of Way, Environmental, Land Acquisition, Compensation)

Commercial Feasibility, Cost and Benefit sharing

New Technological & Threat Trade off -Energy Storage, Hydrogen & Cyber Security

In South Asia Context, OSOWOG will provide further impetus to Power System Integration in South Asia Region & Greening the Cross Border Electricity Trade in the SA Region.

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07 Conclusion &Way Forward

Political Will, Implementation of various Political Consensus

(inter-governmental agreements, bilateral, trilateral, multilateral)

Navigating the Political-Economy, Energy Geopolitics & Strategic Risk.

Navigating Idealism vs realism, being practical

Being familiar with Energy market principles, commercial frameworks & market expectation

Complementary Policy, Regulatory, Market Framework

Steering Energy Security & Energy Interdependence debate, reasonable energy interdependence

Regional Institutional Platforms for Regulations, Planning, System Operation, Market Development

South Asia Energy Grid-Regional Transmission Master Plan, Investment Plans

De-Risking; viability & bankability, Investment facilitation, mobilisation

Reasonable Realism along with a long term vision is key to deepening Cross Border Energy Trade, Energy Market Integration, leads to Economic Clean Energy Transition, Sustainability, Regional stability and Prosperity in South Asia

6. Methodology

Key Outcomes & Derivables from CEA's Transmission Plan for 500 GW Non-Fossil by 2030

1. Executive Summary

The Central Electricity Authority's (CEA) Transmission Plan for integrating over 500 GW of non-fossil capacity by 2030 outlines the most extensive grid expansion blueprint in Indian history. The plan encompasses over 537 GW of renewable energy (RE), including 181.5 GW from newly identified Renewable Energy Zones (REZs) across 8 states, with substantial roles played by Rajasthan, Andhra Pradesh, and Gujarat. It also integrates offshore wind, green hydrogen zones, and energy storage.

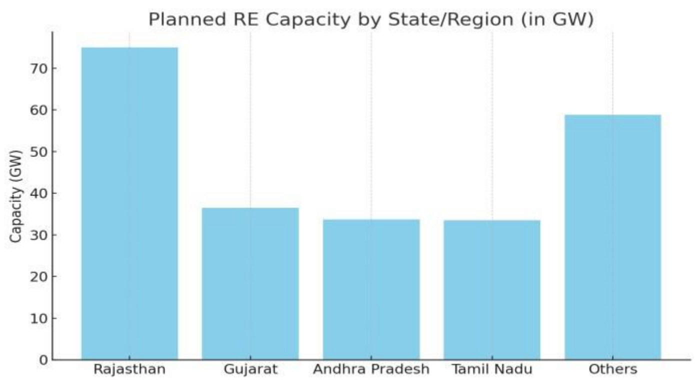
2. Key Targets and Transmission Capacities

- Total RE Capacity Planned: 537 GW
- Transmission lines (ISTS): ~50,890 circuit km
- Substation Capacity: ~433,575 MVA
- Investment: ₹2.44 lakh crores (approx.)
- Phased RE addition: 56 GW by 2025, 62.1 GW by 2027, and 63.4 GW by 2030

3. Regional REZ Development & Integration Plans

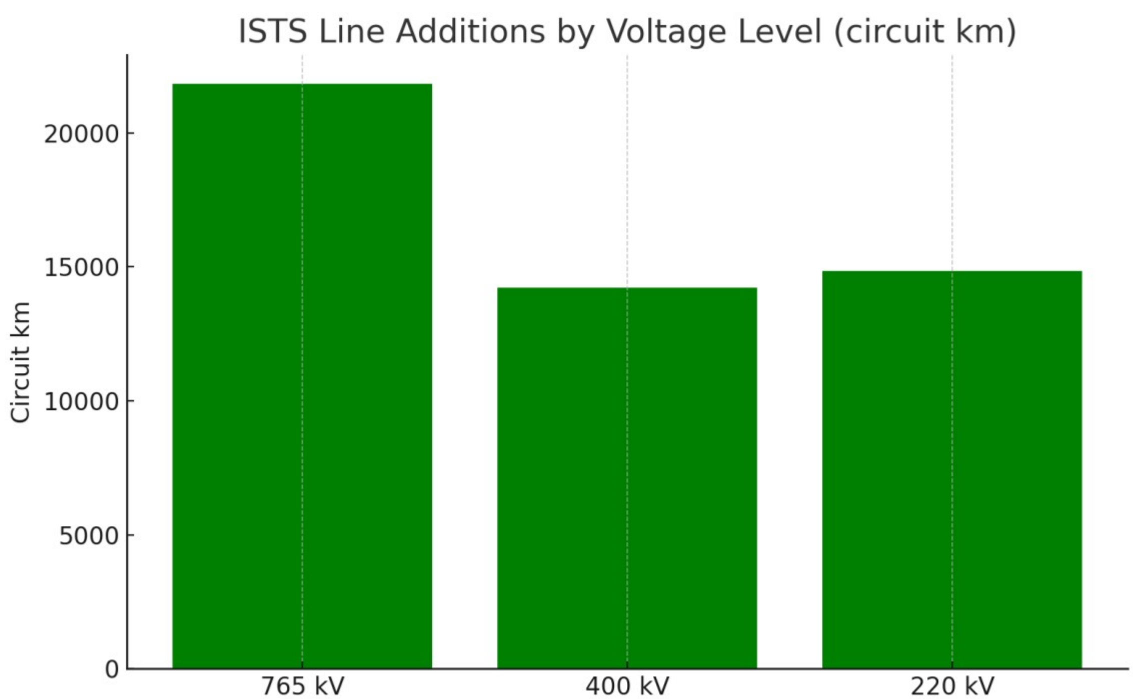
The plan defines transmission schemes for integrating REZs in:
- Northern Region: 75 GW (Rajasthan)
- Western Region: 20.5 GW (Gujarat, Maharashtra, MP)
- Southern Region: 86 GW (AP, Karnataka, Telangana, TN)

It includes both onshore and offshore wind zones and significant use of HVDC corridors.



4. Grid Reinforcement, HVDC and Energy Storage

- High capacity ±800 kV HVDC links (Barmer–Jabalpur, Khavda corridors)
- BESS installations (20–40 GW projected across zones)
- Transmission designs include 765/400/220 kV Pooling stations with flexible reactive compensation (STATCOMs, SVCs)

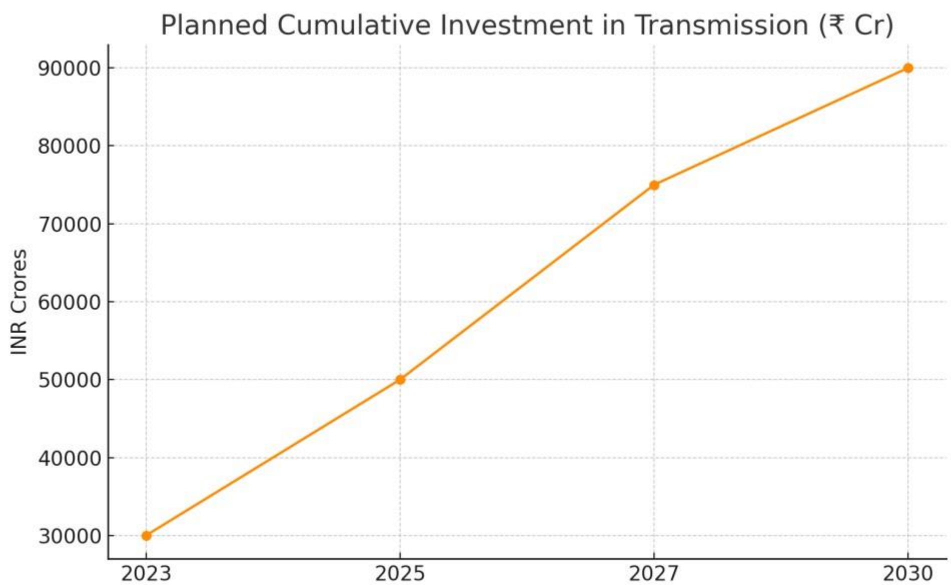


5. Green Energy Corridors and Intra-State Gaps

- GEC-I and GEC-II aim to integrate ~26 GW within states
- States like Maharashtra, MP, and Telangana need to expedite intra-state lines to match ISTS capacity
- Inertia and short-circuit ratio studies to determine synchronous condenser needs

6. Major Outcomes and Derivables

- Transmission phasing is aligned with RE commissioning timelines till 2030
- India to achieve 150,000 MW inter-regional capacity by 2030
- Integration of 5 GW offshore wind (Gujarat, Tamil Nadu) with subsea cables planned
- Prioritization of REZ-linked transmission ahead of generation timelines
- Provisions for green hydrogen hubs and storage-heavy RE clusters



7. Conclusion and Policy Recommendations

The CEA transmission roadmap offers a credible foundation for 500 GW RE integration. Timely execution, inter-agency coordination, and financial closure for transmission bids are critical. Dynamic RE zones need digital load flow analysis and adaptive dispatch strategies.

Policy Suggestions:
- Fast-track ISTS bidding via TBCB
- Mandate BESS-ready pooling substations
- Incentivize synchronous condensers for inertia stability
- Align SLDC upgrades with ISTS rollout

Real-Time Grid and Renewable Generation Data with CTU and State-Level Transmission Plans (India – 2025)

---

1. Introduction

India’s ambitious target of integrating **500 GW of non-fossil fuel energy** by 2030 hinges not only on expanding renewable generation, but also on:

- Real-time monitoring of the grid
- Transmission system readiness (both inter- and intra-state)
- Fast-acting grid flexibility for handling RE variability

This report examines real-time RE generation data, grid operational trends, and gaps between CTU and state-level transmission implementation.

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2. RE Ramping Trends from Real-Time Generation Data

Data from **POSOCO**, **NLDC**, and state-level SLDC dashboards shows a clear daily pattern:

- **Morning ramp-up**: Solar generation sharply rises between 6–10 AM
- **Evening ramp-down**: Solar drops between 5–8 PM while load rises

This creates the classic **“duck curve”**, which stresses thermal/hydro flexibility.

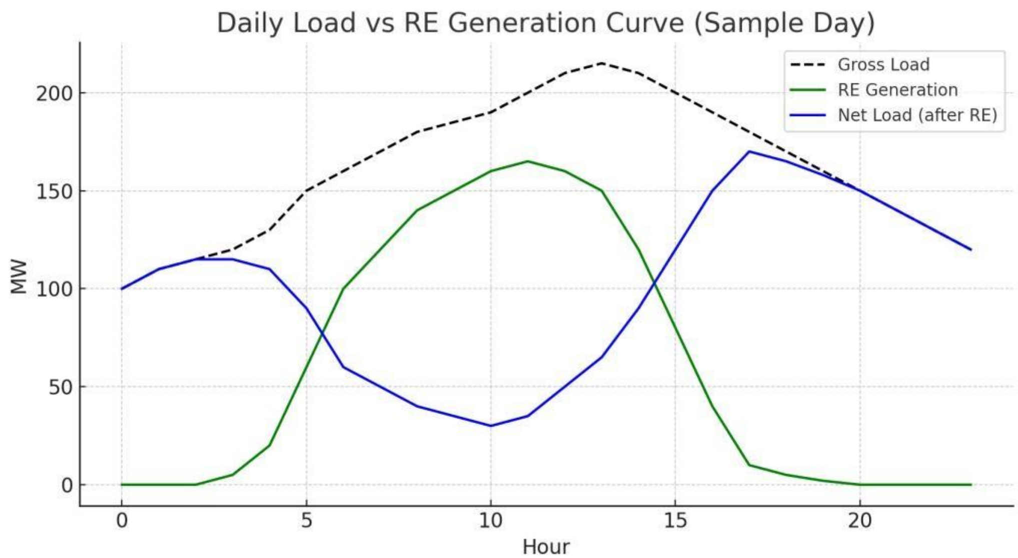

Figure 1 – Daily Load vs RE Generation Curve
(Duck_Curve_RE_vs_Load)

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3. Grid Flexibility Requirements

India’s grid must respond to fast changes in net load due to RE generation swings. Flexible backup is needed in the form of:

- Fast-ramping thermal units
- Hydro generation
- Battery Energy Storage Systems (BESS)

Regional variation exists:

Region	**Required (GW)**	**Available (GW)**
North	15	9
West	12	10
South	10	7
East	6	5

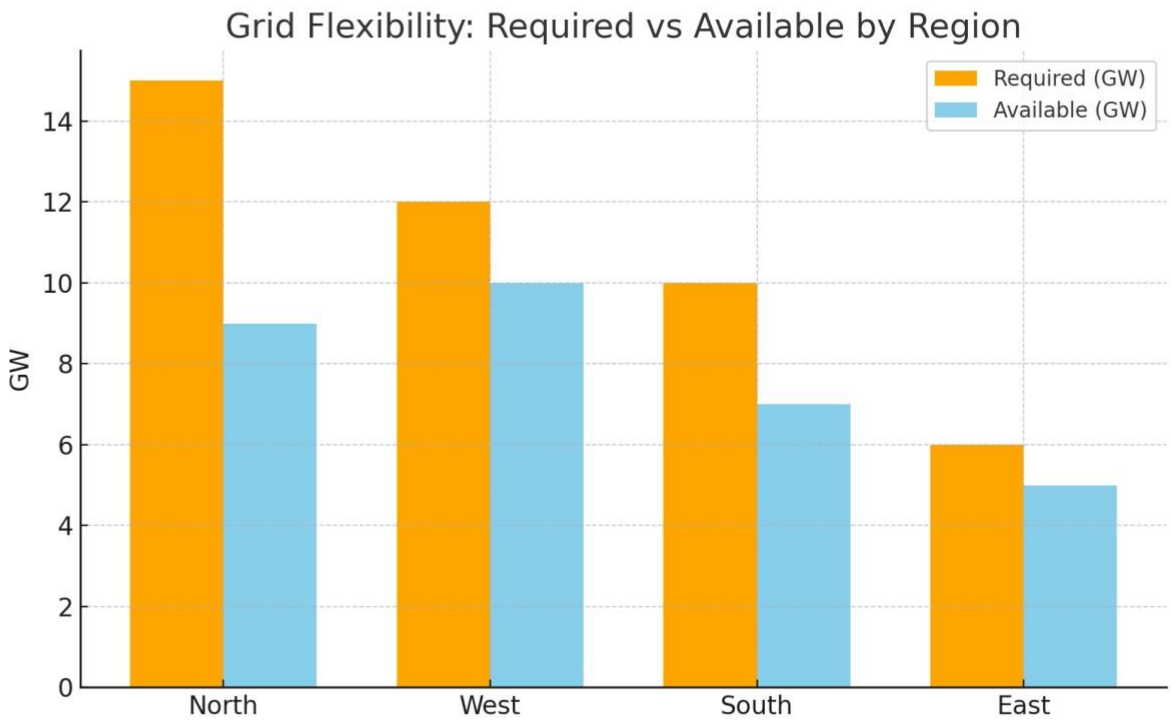

Figure 2 – Flexibility Required vs Available by Region

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4. Real-Time Grid Stability Challenges

Ramping-related issues show up in:

- **System frequency**: Drops during solar ramp-down
- **Voltage fluctuations**: Especially in weak-grid RE zones (e.g., Tamil Nadu, Rajasthan)

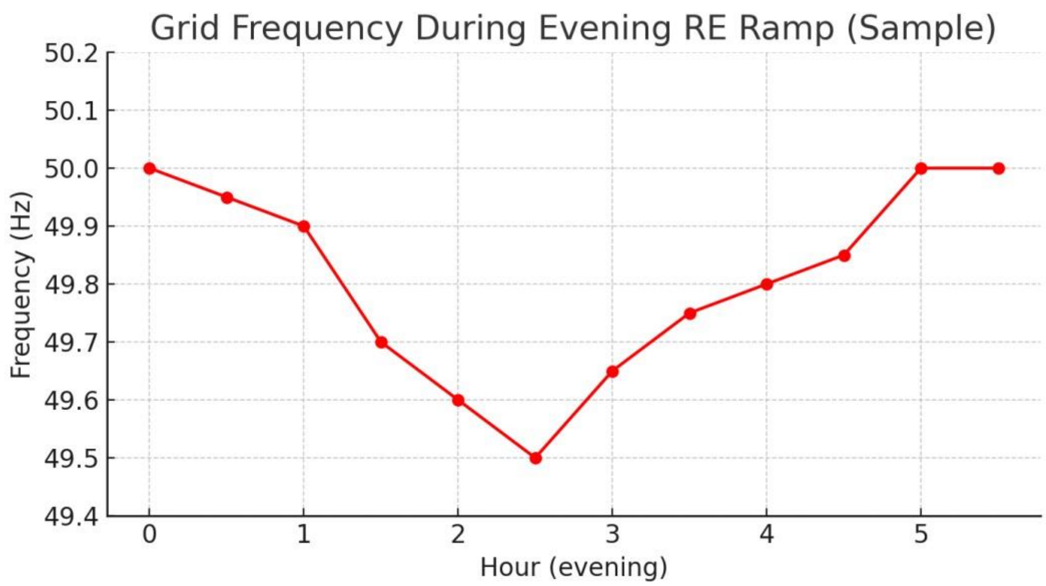

Figure 3 – Frequency Profile During Evening RE Ramp *(Frequency_RE_Ramping)* These fluctuations impact:

- Grid security
- Generator commitment planning
- Curtailment levels in high-RE states

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5. CTU vs State-Level Transmission Planning

India's **Central Transmission Utility (CTU)** has approved:

- Green Energy Corridors (GEC I & II)
- Inter-State Transmission System (ISTS) upgrades for Khavda, Bikaner, and Tamil Nadu REZs

However, state-level intra-transmission additions have **lagged behind** due to:

- Land acquisition delays
- Funding bottlenecks
- Lack of DISCOM coordination

State	Planned (ckm)	Completed (ckm)
Gujarat	6000	4200
Rajasthan	5000	3000
Tamil Nadu	4500	3100
Maharashtra	4000	2700

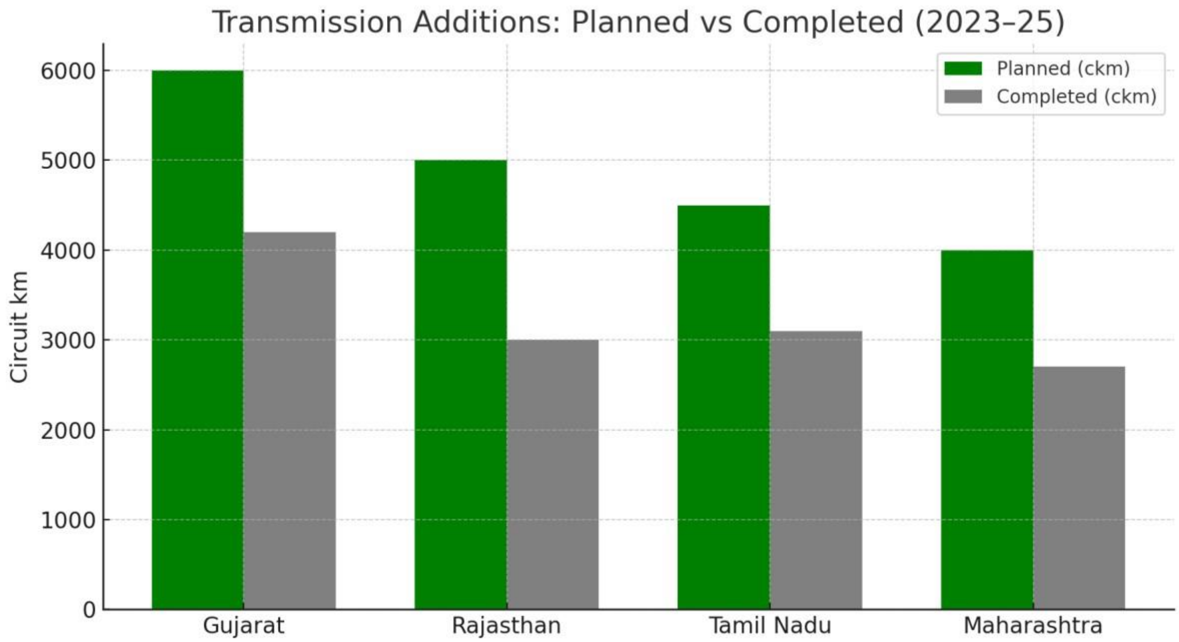

Figure 4 – Transmission Additions – Planned vs Completed
Transmission_Additions_Statewise

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6. Conclusion and Recommendations

India has done well in **RE capacity growth**, but grid flexibility and transmission development must now catch up.
Weaknesses in visibility, forecasting, and intra-state buildout could bottleneck the 2030 targets.

Recommendations:

1. Technical

- Deploy PMUs and SCADA at all RE pooling substations
- Mandate inverter-based fast frequency response

2. Transmission

- Monitor state-wise progress on transmission using CTU dashboards
- Provide Viability Gap Funding (VGF) for key intra-state lines

3. Grid Operations

- Mandate flexibility procurement targets per region
- Encourage flexible generation (hydro, BESS) through real-time markets

Compliance Gap Analysis:

Comparing RE Developer Practices with CEA Technical Standards & Bottlenecks in PPAs and RPO Enforcement (India – 2025)

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1. Introduction

India aims to install **500 GW of non-fossil fuel capacity** by 2030, with nearly **537 GW renewable energy (RE)**, as detailed by the **Central Electricity Authority (CEA)** in its 2022 Transmission Plan. This massive transition is critical for climate commitments (Paris Agreement), energy security, and economic development.

However, physical capacity alone isn't sufficient — this scale of RE integration demands:

- Strict adherence to **technical grid standards**
- Robust **Power Purchase Agreement (PPA)** execution
- Effective enforcement of **Renewable Purchase Obligations (RPOs)**

This report analyzes where **RE developers fall short**, and where **policy enforcement gaps** exist.

---

2. CEA Technical Standards: Summary

The **CEA**, **CERC**, and **CTU** have published the following key requirements for gridconnected renewable developers:

Standard	Requirement
LVRT / HVRT Compliance	Plants must ride-through voltage/frequency disturbances
Ramp Rate Capability	±1.5% of rated capacity per minute (solar & wind)
Forecasting Accuracy	≤10% error in 15-minute block forecasts
Reactive Power Support	0.95 lag to 0.95 lead at interconnection point
Telemetry / SCADA Interface	Real-time data visibility by SLDCs/CTUs

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3. Ground Reality: Current Developer Practices

Despite mandates, developers often **fall short** of the above:

Area	Observed Practice (2024–25)	Compliance Gap

LVRT/HVRT Compliance	Only ~55% of plants tuned to handle faults	Moderate

Compliance

Area	Observed Practice (2024–25)	Gap
Forecasting Accuracy	Errors often exceed 15–20% in key states	High
Ramp Rate Management	Many inverters operate without proper ramp control	High
Reactive Power Provision	Static PF used instead of dynamic reactive control	Moderate
SCADA Telemetry	Missing or delayed from ~30–40% of plants	High

This results in grid instability, curtailment, and reduced trust by DISCOMs.

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4. Policy Bottlenecks: PPA & RPO

A. Power Purchase Agreement (PPA) Issues

- As of 2025, **over 38 GW of RE capacity** is **stranded** due to:
    - Delayed or cancelled PPA signings
    - Tariff renegotiations by state DISCOMs
- Notable bottleneck states: **Andhra Pradesh, Tamil Nadu, Gujarat**

Example: Solar bids awarded in 2022 remained unsigned as of mid-2024.

B. Renewable Purchase Obligation (RPO) Enforcement

State	RPO Target (2024–25)	Actual Fulfillment	Gap
Gujarat	17.0%	14.2%	Moderate
Maharashtra	18.5%	12.9%	High
Rajasthan	21.0%	19.8%	Low
Tamil Nadu	18.0%	13.1%	High
Bihar	14.5%	8.7%	Severe

Many states under-procure RE despite availability. Weak enforcement by SERCs is a key issue.

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5. Summary Table: CEA Standard vs. Practice

Category	CEA Requirement	Developer Practice	Gap

			Level
Ramp Rate	±1.5%/min	Often uncontrolled	High

Category	CEA Requirement	Developer Practice	Gap Level
Forecast Accuracy	≤10% error	~15–20% error	High
Reactive Power	Dynamic (0.95 lag–lead)	Static PF in many cases	Moderate
SCADA/Telemetry	Mandatory	Partial/Missing	High
PPA Execution	<6 months post-auction	9–18 months delay	High
RPO Compliance	≥90% compliance	50–80% in many states	High

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6. Recommendations

Technical Enforcement

- CERC/CEA must **mandate LVRT, ramp, and forecasting standards** through audited commissioning tests
- **Grid-forming inverter technology** should be incentivized for new solar/wind installations

PPA Reform

- CTU should monitor all PPAs via a **centralized dashboard**
- Penalize delays >180 days post-bid

RPO Strengthening

- SERCs should:
    - Issue fines for under-procurement
    - Offer credit-trading or cross-state RPO settlement

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7. Conclusion

India’s RE sector has grown fast — but **compliance enforcement hasn’t kept up**. If developers adhere to CEA norms and if PPA/RPO issues are streamlined, **500 GW renewable integration** will be both **reliable and resilient**.

7.TECHNICAL SOLUTIONS & RECOMMENDATION

TECHNICAL SOLUTIONS

1.Battery Energy Storage Systems (BESS)

Overview:

BESS refers to grid-connected batteries that store electricity when production exceeds demand and supply it back when demand rises. They play a pivotal role in **flattening the renewable generation curve** and **enhancing grid resilience**.

Technical Functions:

- **Energy Arbitrage**: Shifts energy from off-peak to peak hours.
- **Frequency Regulation**: Responds in milliseconds to frequency deviations.
- **Load Levelling & Peak Shaving**: Reduces peak load on the grid.
- **Voltage Support**: Supplies/absorbs reactive power.
- **Black Start**: Can re-energize the grid after a blackout without external power.

Technologies:

- **Lithium-ion**: High efficiency, dominant tech globally.
- **Flow Batteries (Vanadium Redox)**: Suitable for long-duration storage.
- **Sodium-Sulfur (NaS)**: High energy density, long lifespan.
- **Hybrid Systems**: Combine BESS with diesel, PV, or wind.

Deployment Status in India:

- Pilot projects by **SECI**, **NTPC**, and **Tata Power**.
- MNRE aims to support 4 GWh initial deployment.
- India Energy Storage Alliance (IESA) projects 100+ GWh needed by 2030.

Strategic Benefit:

Enables **non-disruptive integration** of variable solar and wind generation into India's grid.

2. Flexible Hydro and Gas-Based Plants

Overview:

Flexible hydro and gas plants are essential **balancing assets** that provide dispatchable power. Their quick ramping capability allows them to compensate for RE fluctuations.

Types & Technical Aspects:

a. Pumped Hydro Storage (PHS):

- Works like a **mechanical battery**.
- Pumps water uphill during RE surplus.
- Releases water to generate power during peak demand.
- 75% round-trip efficiency.
- Capacity: Over 90 GW potential in India; ~5 GW operational.

b. Gas-Based Power Plants:

- **Open Cycle Gas Turbines (OCGT)**: Fastest ramping, ~10 min startup.
- **Combined Cycle Gas Turbines (CCGT)**: More efficient, slower ramping.
- Used as **peaker plants** or spinning reserves.

India's Scenario:

- Low PLF of existing gas plants due to fuel issues; need policy support for flexible operation.
- **Tehri PSP**, **Srisailam**, and **Koyna** are examples of PHS projects.

Strategic Benefit:

Forms the **backbone for frequency regulation and ramping**, filling gaps left by solar/wind variability.

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3. Synchronous Condensers (SCs)

Overview:

Synchronous Condensers are **rotating machines** that provide **non-active services** like **inertia, reactive power**, and **fault current**. They simulate the **electromechanical behavior of traditional generators**.

Key Grid Services:

- **Inertia Provision**: Stabilizes frequency during sudden load changes.
- **Reactive Power Support**: Maintains voltage profile.
- **Short-Circuit Power**: Helps detect faults.
- **Fault Ride-Through**: Supports the grid during disturbances.

 Technical Specs:

- Operate at 50 Hz synchronously.
- Can include **flywheels** for added inertia.
- Often retrofit from old thermal generators.

Deployment Status:

- Recommended by **CEA** for RE zones.
- Installed in **Germany, Australia**, and now in **India** in select corridors.
- NTPC exploring retrofitting decommissioned coal plants.

Strategic Benefit:

Restores **system strength and stability** in weak, RE-dominated regions.

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4. Distributed HVDC Nodes

Overview:

HVDC technology allows bulk power transfer with **lower losses** and **precise control**. Distributed HVDC nodes spread across the grid help transmit renewable power from **remote generation zones** to **distant load centers**.

Technical Highlights:

- **Voltage Source Converters (VSC-HVDC)**:
  - Suitable for multi-terminal and offshore wind integration.
  - Independent control of active/reactive power.
- **Line Commutated Converters (LCC-HVDC)**:
  - Suited for bulk long-distance transmission.
  - Lower losses but less control flexibility.

 Use Cases in India:

- **Leh–Kaithal HVDC Project**: Transmit 13 GW from Ladakh solar parks.
- **Chhattisgarh–Tamil Nadu GEC links**.
- Multi-terminal HVDC concept proposed for RE-rich zones.

Strategic Benefit:

Supports **RE evacuation over long distances**, reduces AC congestion, enables **zonal balancing**.

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5. Dynamic Control & Forecasting Systems

Overview:

These systems use **real-time monitoring**, **AI-based forecasting**, and **automated control** to manage RE variability, grid constraints, and dispatch planning.

Functional Components:

- **Renewable Forecasting Systems (RFS)**: o Predict RE generation using meteorological data, satellites, and AI.
- **Energy Management System (EMS)**:
  - Centralized control for dispatch and reliability.
- **Supervisory Control and Data Acquisition (SCADA)**:
  - Gathers real-time operational data.
- **Phasor Measurement Units (PMUs)**:
  - Provides high-speed measurements for dynamic response.

Implementation in India:

- POSOCO mandates **state-wise forecasting**.
- **AGC pilots** in NTPC and NLDC under implementation.
- SCADA under **National Smart Grid Mission** (NSGM).

Strategic Benefit:

Enables **data-driven, predictive grid operation** to manage high RE without compromising stability.

INFRASTRUCTURE SOLUTIONS

1. Green Energy Corridors (GEC)

What it is:

A national transmission infrastructure project to **evacuate renewable energy** (mainly solar and wind) from generation-rich zones to demand centers.

Key Features:

- **Intra-state and inter-state transmission lines**
- Substations, dynamic reactive power compensation (STATCOM/SVC)
- SCADA-enabled smart monitoring

GEC Phase-I & II:

- **Phase I**: 9,400 km transmission lines and 19,000 MVA substations in 7 RE-rich states.
- **Phase II**: Focus on states with new solar/wind parks — Gujarat, Tamil Nadu, Rajasthan, Andhra Pradesh.

Why It's Important:

- Prevents **renewable curtailment** due to evacuation bottlenecks.

- Ensures **grid readiness for utility-scale solar parks (UMREPPs)** and wind zones.
- Connects to **battery storage hubs and load centers**.

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2. Offshore Wind Integration

What it is:

Harnessing **high-potential offshore wind** (OW) from India's coastal zones (Tamil Nadu, Gujarat) to the grid.

 India's Potential:

- Over **70 GW** estimated along Gujarat and Tamil Nadu coasts.
- MNRE targets **30 GW offshore wind by 2030**.

Grid Integration Requirements:

- **Offshore HVDC/AC substations**
- Submarine cable transmission infrastructure
- Onshore **receiving stations and reactive power management**
- Environmental and marine spatial planning

Why It's Important:

- Offshore wind is **more consistent** than onshore wind.
- **Diversifies the RE mix** to reduce solar dependence.
- Brings RE closer to coastal load centers (e.g., Mumbai, Chennai).

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3. Regional Grid Planning

What it is:

Strategic design and coordination of grid assets across **regions, states, and renewable zones** to manage large-scale RE integration.

Features:

- **Zonal balancing systems**
- **Transmission Congestion Forecasting Tools**
- Real-time market optimization
- Unified SCADA/EMS platforms
- Inclusion of **Distributed Energy Resources (DERs)** **Regional Examples:**
- Southern Grid: High wind integration challenge.
- Western Grid: Major solar generation zones.
- North-Eastern Grid: Hydro + solar potential.

Why It's Important:

- Avoids **RE oversupply in localized regions**.
- Allows **optimal dispatch** across multiple grids.
- Supports **MBED (Market-Based Economic Dispatch)** vision by CERC.

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4. OSOWOG – "One Sun One World One Grid"

What it is:

India-led global initiative to **interconnect solar and renewable resources across countries**, enabling **transnational electricity exchange**.

Vision:

- "Sun Never Sets" energy flow: Solar energy flows westward with the sun.
- Start with interconnections in **South Asia, Middle East, Africa**.
- Backed by **ISA (International Solar Alliance)** and World Bank.

Phased Implementation:

1. **South Asia interconnection** (India–Nepal–Bhutan–Bangladesh–Sri Lanka)

2. **Middle East – South Asia**
3. **Global solar grid exchange platform**

Technical Enablers:

- HVDC links (e.g., India-Sri Lanka, UAE–India)
- Unified cross-border energy trading systems
- Common market rules, balancing, and settlements

Why It's Important:

- Enables **renewable trading across time zones**
- Reduces global RE curtailment and enhances grid security
- Establishes India as a **RE grid hub and power exporter**

REGULATORY & MARKET SOLUTIONS

1. Renewable Purchase Obligation (RPO)

What It Is:

RPOs are legally binding mandates requiring **discoms, open access consumers, and captive users** to procure a **minimum percentage of electricity** from renewable sources.

Structure:

- **Solar RPO** (specific to solar)
- **Non-solar RPO** (wind, small hydro, etc.)
- Recently added: **Energy Storage Obligation (ESO)** component

National Target:

- **43.33%** of electricity consumption to come from RE by **2030** (MoP, 2022)

Issues:

- Many discoms fail to comply due to financial or operational constraints.
- Weak enforcement by state regulators (SERCs).

Why It's Important:

- Creates **demand pull** for renewable energy.
- Ensures **guaranteed market** for RE developers.
- Drives **bankability of projects**.

□□ **Solutions Needed:**

- Stronger enforcement by **CERC and SERCs**.
- Penalty mechanisms for non-compliance.
- Market-based compliance tools (RECs, green markets).

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2. Power Purchase Agreement (PPA) Enforcement

What It Is:

PPAs are long-term contracts signed between **RE developers and discoms** for selling power at a fixed tariff.

Issues in India:

- **Delays in signing/commissioning** by discoms.
- **Renegotiation of tariffs** post-auction (especially in Andhra Pradesh, Gujarat).
- **Payment delays** to RE generators (avg. >6 months in some states).

Why It's Important:

- PPAs are the **backbone of project financing** in RE (70–80% debt-financed).
- Bankability, investor confidence, and project commissioning depend on enforcement.

□□ **Solutions Needed:**

- Legal sanctity of PPAs must be upheld — **no retrospective tariff changes**.
- **Central Payment Security Mechanism (PSM)** to be strengthened.
- State regulators must penalize delays in honoring signed PPAs.

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3. Tender Process Reform

What It Is:

The tendering mechanism (primarily through SECI and state agencies) allocates RE projects through **competitive bidding**.

Issues:

- **Unviable bids** to win contracts (race to the bottom).
- **Delays in land allocation, transmission readiness**.
- Inflexible timelines, poor risk-sharing in standard bidding documents (SBDs).
- Lack of location-specific pricing (uniform tariffs).

Why It's Important:

- Determines **pace and quality of RE capacity addition**.
- Affects **developer interest, project completion rate**, and tariffs for consumers.

□□ **Reforms Needed:**

- **Hybrid auction models** (tariff + viability index)
- **Pre-approved land and transmission (plug-and-play)** tenders
- **Incentives for early commissioning**
- Segregate tenders based on **location, storage, hybrid, round-the-clock (RTC)** attributes.

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4. Incentives for Storage-Backed RE

What It Is:

Encouraging **integration of battery energy storage** with solar/wind to make renewable energy **dispatchable** and **grid-friendly**.

Key Models:

- **RE + Storage Tenders** (e.g., SECI RTC, Peak Power)
- **Standalone storage tenders** (1 GWh +)
- **Energy-as-a-Service** business models
- **VGF and capital subsidy** for battery capex **Why It's Important:**

- Enables **firm, round-the-clock RE supply**
- Reduces **curtailment** and improves grid reliability
- Opens path for **flexible market participation** (ancillary services, peak power)

□□ **Incentives & Reforms Needed:**

- **Viability Gap Funding (VGF)** or upfront subsidy for battery integration
- **Time-of-Day (ToD) tariffs** to make storage commercially viable
- **Tax waivers** and production-linked incentive (PLI) for battery manufacturing
- Mandated **storage procurement obligations** for discoms (similar to RPO)

FINANCIAL SOLUTIONS

1. **Blended Public-Private Finance**

What It Is:

A financing model that **strategically uses public funds (grants, guarantees, or concessional loans)** to attract and **de-risk private capital** for clean energy projects.

Structure:

- **Public Capital** (Govt., MDBs, DFIs): Provides first-loss, subordinate, or concessional support.
- **Private Investors** (Banks, Funds, Corporates): Bring in commercial capital at scale.
- **Risk-Sharing Mechanisms**: Guarantees, credit enhancements, insurance.

Why It's Important:

- RE sectors like **battery storage**, **offshore wind**, and **grid upgrades** are still considered **high-risk** by private financiers.
- Blended finance **improves bankability**, reduces Weighted Average Cost of Capital (WACC), and **crowds in private capital**.

□□ **Indian Applications:**

- **SECI VGF schemes** use public funds to lower solar tariffs.
- **IREDA** exploring blended finance for solar + storage tenders.
- **NABARD, NIIF, and GCF** co-financing decentralized RE.

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2. Concessional Capital for Storage & Transmission

What It Is:

Low-cost, long-tenure financing for grid-scale **battery energy storage systems (BESS)**, **pumped hydro**, and **transmission infrastructure** that supports RE.

Why It's Needed:

- High upfront capital cost (e.g., ₹7–10 crore/MWh for BESS).
- **Transmission investments** are slow-repaying but essential for RE evacuation.
- Commercial financiers avoid such assets without **cost-reflective returns**.

Sources of Concessional Capital:

- **Multilateral Institutions**: World Bank, ADB, KfW, JICA
- **Sovereign Green Bonds**
- **Results-Based Financing (RBF) Schemes** • **Interest subvention programs** by MoP, MNRE

□□ **Current Initiatives:**

- **World Bank – $1 Billion facility** for BESS under discussion.
- **KfW-GIZ loans** for Green Energy Corridor development.
- MNRE considering **interest-free capital subsidy** for pilot storage projects.

Benefits:

- Accelerates rollout of **firm RE (RTC RE)** and **inter-state green corridors**.
- Reduces electricity cost from RE + Storage, enabling **market parity**.

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3. Access to Global Climate Funds

What It Is:

India tapping into **international climate finance** mechanisms to fund clean energy transition, especially in areas with **high public benefit but low financial returns**.

Major Global Funds:

- **Green Climate Fund (GCF)**
- **Climate Investment Funds (CIF)**
- **Global Environment Facility (GEF)**
- **Just Energy Transition Partnerships (JETP)**
- **Adaptation Fund**

How They Help:

- Provide **grants, low-interest loans, guarantees** to reduce risk and WACC.
- Focus on **mitigation and adaptation** benefits.
- Can fund **climate-resilient transmission**, **discom reform**, **smart metering**, etc.

□□ **India's Engagement:**

- GCF has approved funding for:
    - **SECI solar-wind hybrid parks**
    - **EESL energy efficiency projects**
    - **IREDA financing lines**
- India is also negotiating a **Just Energy Transition Partnership (JETP)** with G7.

Importance:

- Eases pressure on domestic fiscal resources.
- Allows India to **scale up clean infrastructure faster**.
- Encourages international partnerships in **climate-aligned finance**.

“**To successfully integrate 500 GW of renewable energy by 2030, India must implement a holistic strategy combining technology, policy, infrastructure, and finance”**:

Grid Infrastructure & Technology

- Expand **Green Energy Corridors** and deploy **distributed HVDC nodes** for efficient RE transmission.
- Integrate **offshore wind** and strengthen **regional grid planning** with smart, resilient networks.
- Invest in **battery storage**, **pumped hydro**, and **flexible gas/hydro plants** to balance variable RE.

System Operations & Stability

- Deploy **synchronous condensers**, **real-time forecasting**, and **dynamic control systems** for voltage, frequency, and inertia support.
- Improve **load and generation forecasting** using AI and PMU-based control systems.

Policy & Regulatory Reform

- Strengthen enforcement of **Renewable Purchase Obligations (RPOs)** and **Power Purchase Agreements (PPAs)**.
- Reform the **tender process** to include location, storage, and hybrid readiness.

Finance & Market Development

- Use **blended public-private finance** to de-risk large-scale clean energy investments.
- Provide **concessional capital** for storage and transmission infrastructure.
- Expand access to **global climate funds** and launch incentives for **storage-backed RE projects**.

8.Expected Deliverables

As India moves toward its 2030 goal of integrating 500 GW of non-fossil fuel energy capacity—predominantly renewables—it is crucial to produce actionable, data-driven, and policy-relevant outputs. The following deliverables are designed to provide technical insights, policy direction, and a clear roadmap for implementation aligned with CEA, CTU, CERC, and MoP frameworks.

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1. GIS-Based Mapping of Renewable Energy Zones vs. Transmission Buildout

- **Objective**: To spatially analyze and visualize the alignment (or gaps) between identified Renewable Energy Zones (REZs) and planned/ongoing transmission infrastructure.
- **Features**:
  - Layered GIS maps highlighting:
    - State-wise REZ capacity allocations (e.g., Rajasthan: 75 GW, Andhra Pradesh: 51 GW)
    - Status of ISTS and Green Energy Corridor (GEC) projects
    - Locations of upcoming BESS installations and pooling substations
  - Identification of **critical congestion hotspots** and **under-served RE zones**
  - Integration of HVDC corridors and offshore wind transmission (e.g., Tamil Nadu, Gujarat)
- **Outcome**: A visual planning tool for central and state agencies to synchronize RE deployment with transmission readiness and prioritize grid expansion.

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2. Draft Policy & Regulatory Reform Framework

- **Objective**: To recommend actionable policy reforms and regulatory enablers needed to unlock RE integration, address developer bottlenecks, and ensure compliance with CEA/CERC norms.
- **Key Focus Areas**:
  - **PPA Enforcement**: Fast-track signing, standardization of terms, and penalty for delays
  - **RPO Strengthening**: Enforcement of state-level Renewable Purchase Obligations with penalty and trading mechanisms
  - **Storage Procurement Obligation**: Introduce mandates and incentives for discoms to procure battery storage
  - **Grid Code Upgrades**: Align technical standards for LVRT, HVRT, ramping, and SCADA telemetry with real-time RE variability

- **Tendering Reform**: Design plug-and-play tenders with pre-approved land and transmission access

- **Outcome**: A structured reform package for use by MoP, CERC, and state regulators to accelerate and de-risk RE integration.

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3. Prioritization Roadmap: Short-, Medium-, and Long-Term Actions (2025–2030)

Timeline	Priority Actions
Short-Term (2025–2026)	- Expedite GEC-II & ISTS rollout in REZs (e.g., Khavda, Bhadla) - Commission minimum 10 GW BESS pilot capacity - Mandate real-time grid monitoring via PMUs, SCADA - Resolve stranded RE projects (~38 GW) due to PPA or grid delays
Medium-Term (2026–2028)	- Operationalize offshore wind transmission links - Implement dynamic scheduling and MBED markets - Begin construction on OSOWOG Phase I interconnections - Enforce RPO and ESO compliance tracking with penalties
Long-Term (2028–2030)	- Achieve 150,000 MW inter-regional transmission capacity - Complete integration of 51.5 GW BESS - Operationalize grid-forming inverter standards - Ensure 100% RE zone-to-load center dispatchability through adaptive grid tools

- **Outcome**: A phased action plan that aligns grid upgrades, regulatory milestones, and RE integration targets for a resilient 2030-ready power system.

Conclusion

This project aims to deliver a **comprehensive, data-driven, and multi-stakeholder strategy** to support India's ambitious transition toward **500 GW of renewable energy by 2030**. Grounded in the Central Electricity Authority's (CEA) transmission roadmap and national regulatory frameworks, the study brings together:

- **Technical modeling** of renewable energy integration challenges such as grid stability, transmission congestion, and storage needs.

- **Policy and regulatory analysis** to identify bottlenecks in PPA execution, RPO compliance, and transmission coordination.
- **GIS-enabled spatial diagnostics** to map Renewable Energy Zones (REZs) against transmission buildout and storage deployment.
- **A phased action plan** recommending short-, medium-, and long-term interventions—spanning infrastructure, market mechanisms, and institutional reforms.

By addressing **real-world grid challenges**—ranging from ramping and curtailment to land acquisition and cross-agency coordination—this project will present a **credible implementation roadmap**. It will be relevant for central and state utilities, policymakers, regulators, and private developers.

In sum, this project is not only a technical exercise but a **strategic contribution** to India's clean energy leadership, energy security, and climate commitments. If executed in coordination with key stakeholders, the solutions proposed herein can directly accelerate the country's progress toward a **resilient, inclusive, and decarbonized power system** by 2030.