Challenges of Renewable Energy Integration

21 January 2026

VRE integration is essential to meet India's climate commitments amid growing RE penetration and falling solar and wind costs

500 GW Non-fossil fuel power generation capacity by **2030**

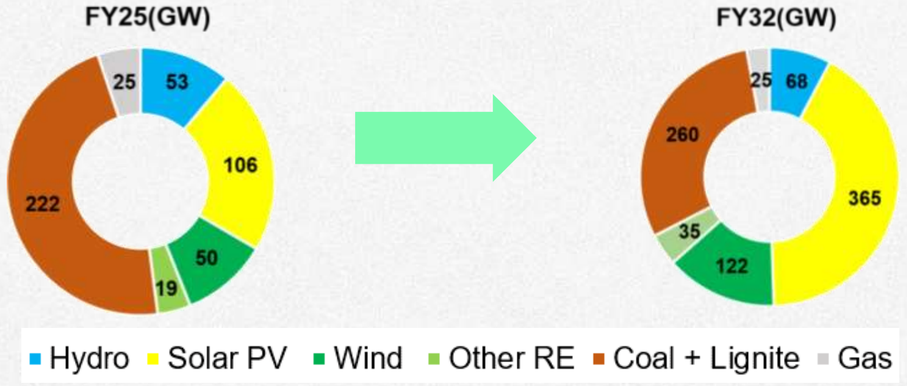
Share of energy requirement to be met by renewable energy by **2030** **50%**

3 billion tonnes Reduction in total projected carbon emissions by **2030**

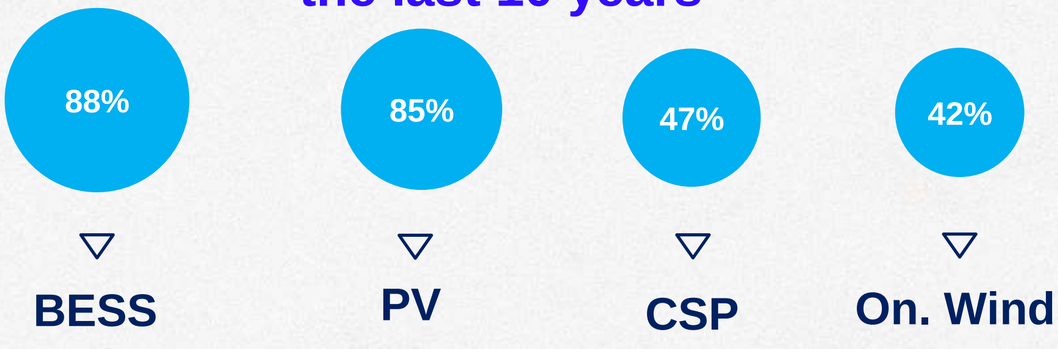
Reduction in carbon intensity of its economy by **2030** **45%**

Net Zero Targeted emissions to be achieved by **2070**

India's VRE capacity is expected to increase over 212% in next 7 years



RE and BESS costs declined rapidly over the last 10 years



The cost decline is more pronounced in last three years

Sources: UNFCC, IEA, IRENA

With rising VRE penetration, duck-curve effects are now evident in the system load profile-signaling India's Phase 3 VRE integration, led by high-RE states

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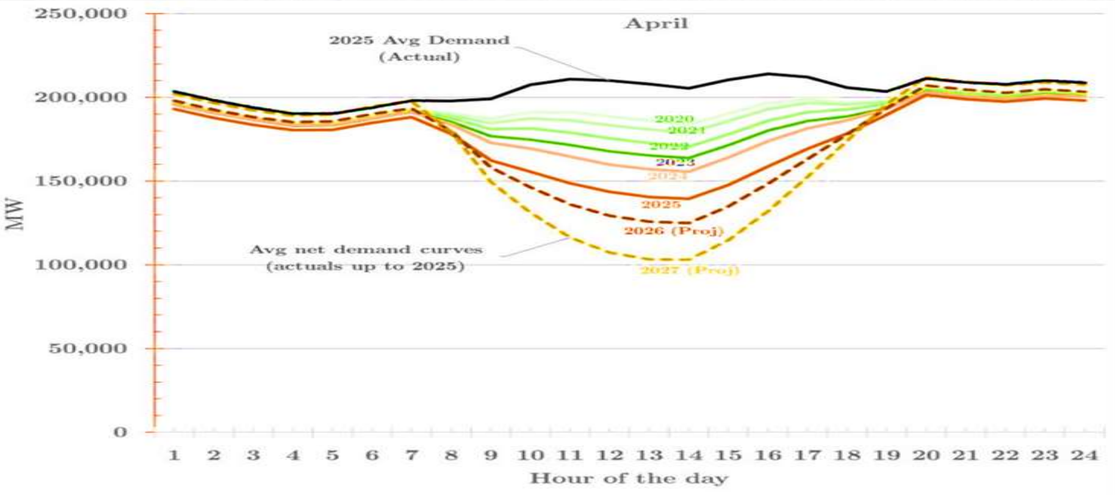
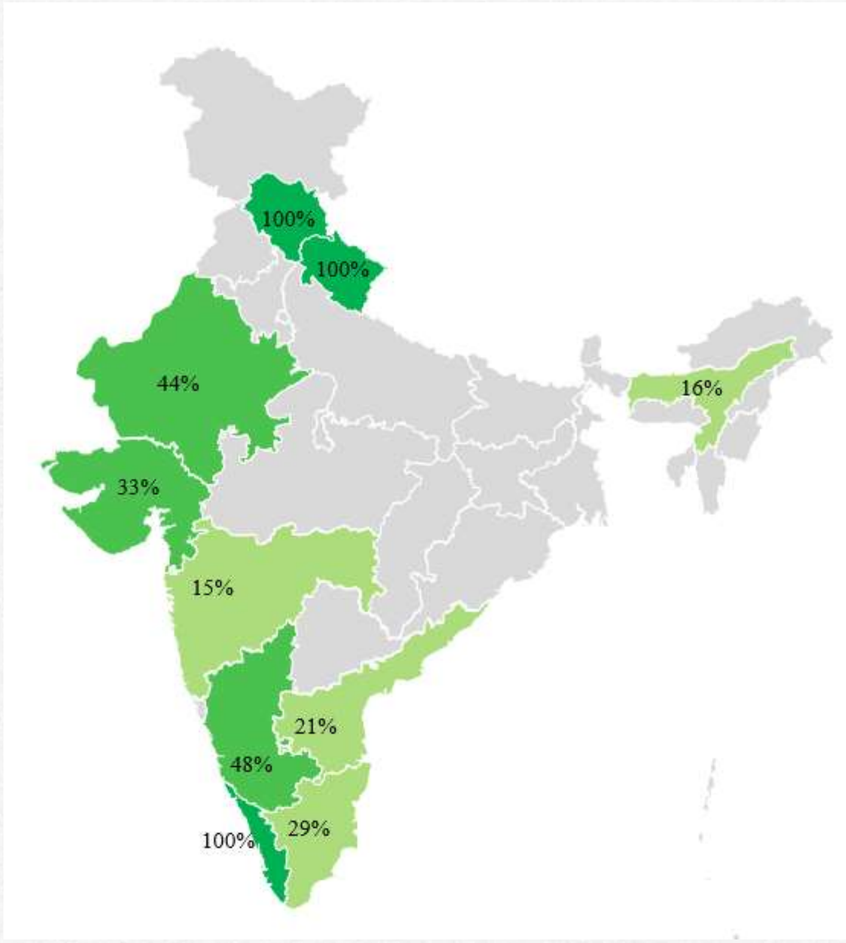
Six phases of variable renewable energy integration, IEA

01	VRE has no significant impact at the system level
02	VRE has a minor to moderate impact on the system
03	VRE determines the operation pattern of the power system
04	VRE meets almost all demand at times
05	Significant volumes of surplus VRE across the year
06	Secure electricity supply almost exclusively from VRE

Widening belly of the "Duck Curve"



Maximum demand met by RE generation at a particular instance (Top 10 states)

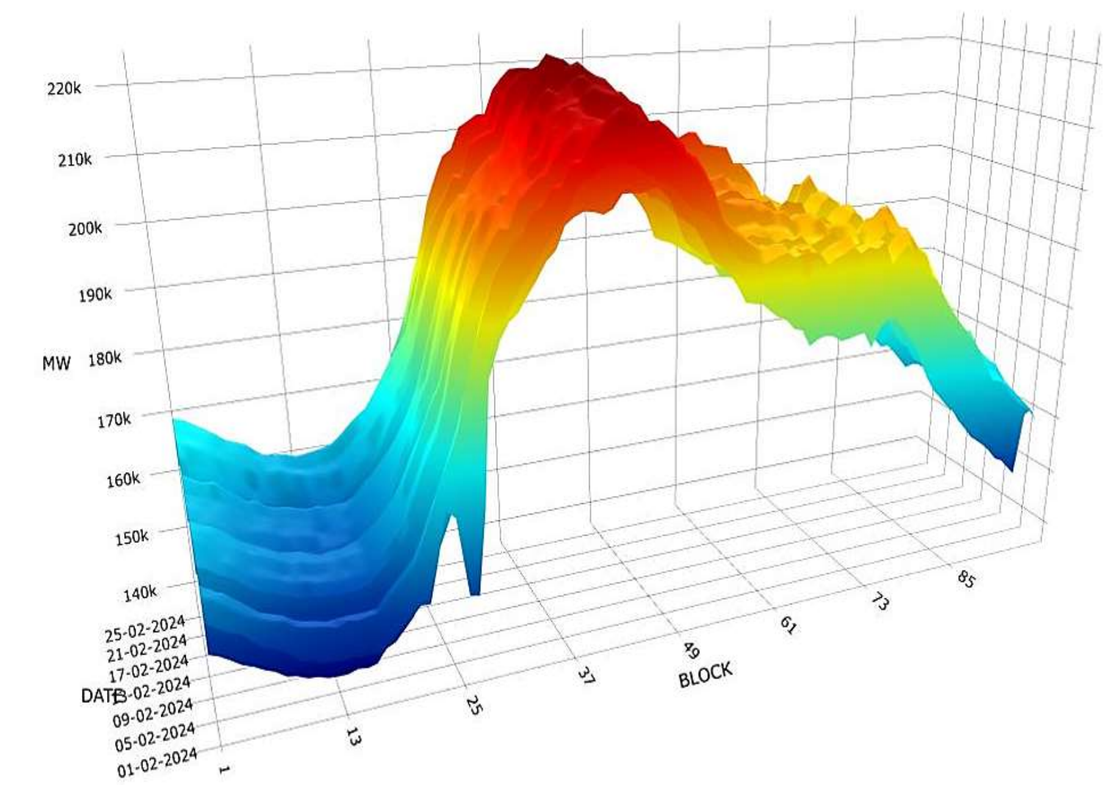


Sources: IEA, Grid-India

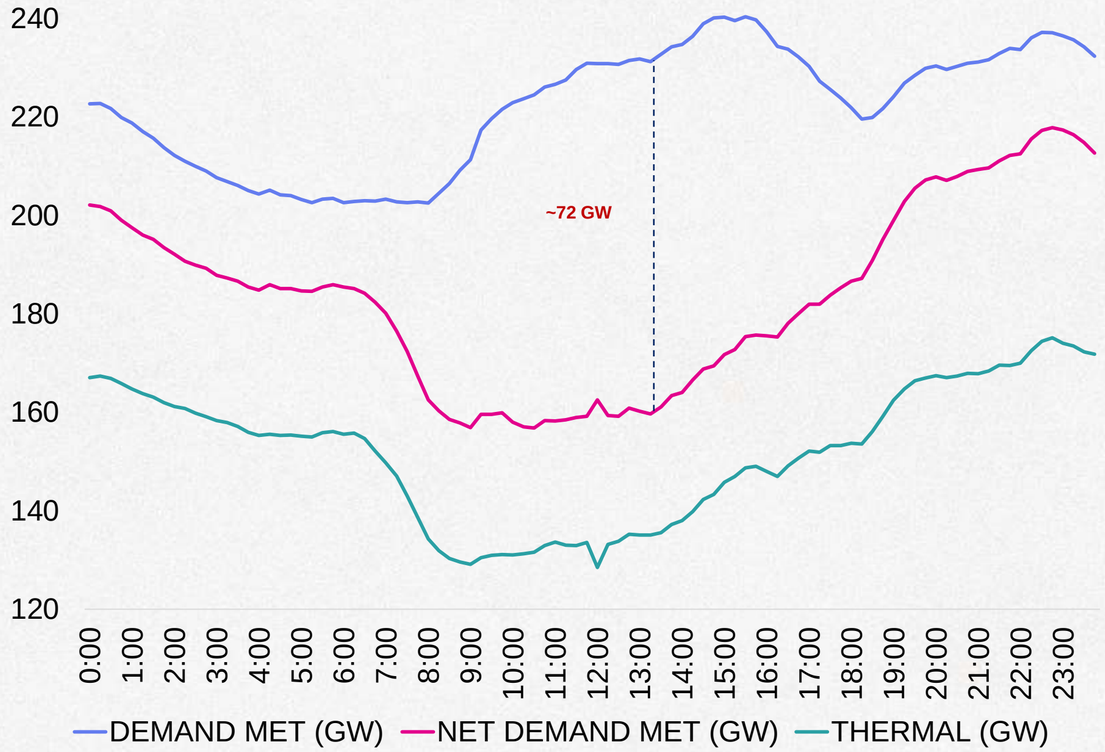
Key Challenges in VRE Integration

Growing need of flexibility in the grid

All India Demand (MW) for Feb 2024



Demand (GW) on 9 Jun 2025



- Typical Ramp rate ~ 250-300 MW/min
- Special Days ~ 500 MW/min

- Duck curve reveals growing midday surplus and evening ramping challenges

Source: Grid-India

Low RE-generation periods tighten resource adequacy margins, necessitating availability of adequate firm capacity and reserves

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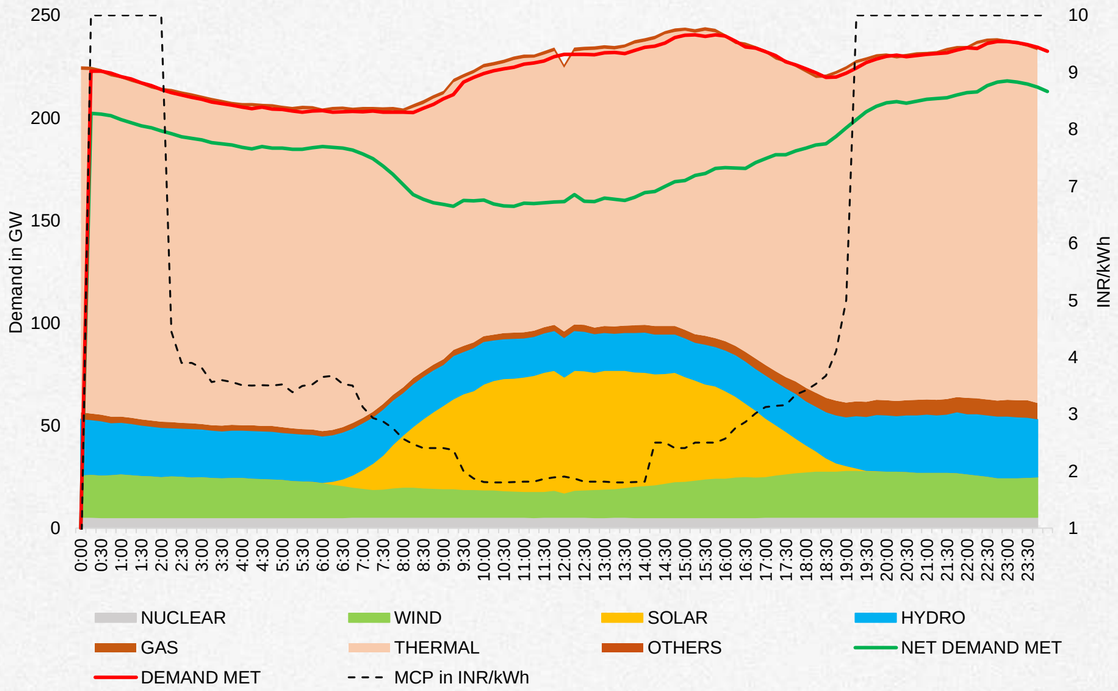
Others

Grid Security & Stability

Resource Adequacy Concerns

Increasing Ramping Requirement

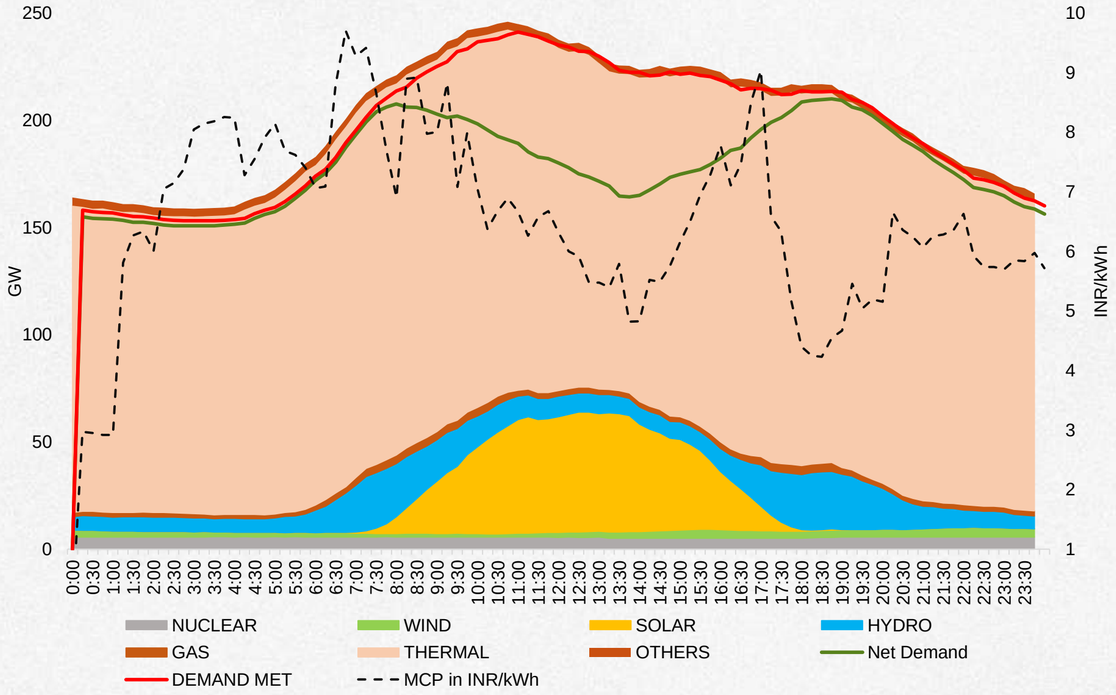
All India Generation (Area Plot) 9 June 2025



	Demand	Time	Net Demand	Nuclear	Thermal	Gas	Hydro	Wind	Solar	% RE	Day Peak
Peak (solar hrs)	240	15:30 PM	175	5	149	4	19	19	46	35%	Yes
Peak (non-solar hrs)	238	22:30 PM	217	5	174	8	30	20	0	21%	No

Demand & Generation are in GW. Time is in hh:mm, solar hrs:0600-1800 and non-solar hrs:0000-0600 & 1800-2400

All India Generation (Area Plot) 31 Dec 2025

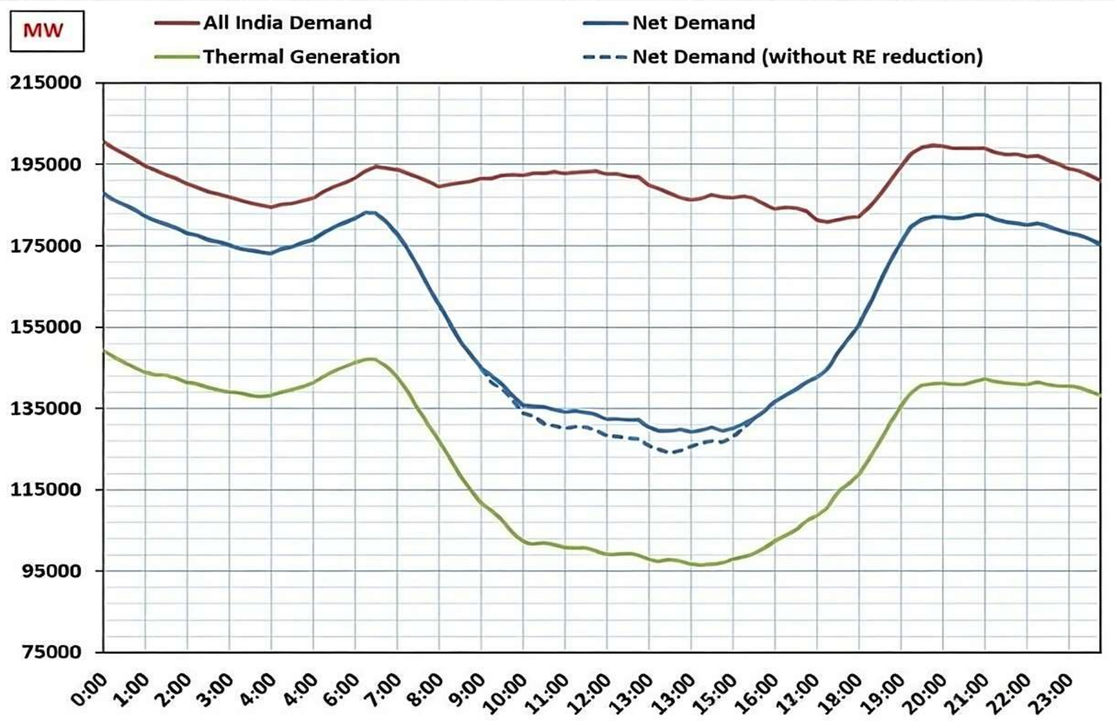


	Demand	Time	Net Demand	Nuclear	Thermal	Gas	Hydro	Wind	Solar	% RE	Day Peak
Peak (solar hrs)	241	10:45 AM	189	6	169	4	12	1	50	26.54%	Yes
Peak (non-solar hrs)	213	18:30 PM	210	5	173	4	27	3	0	14.30%	No

Demand & Generation are in GW. Time is in hh:mm, solar hrs:0600-1800 and non-solar hrs:0000-0600 & 1800-2400

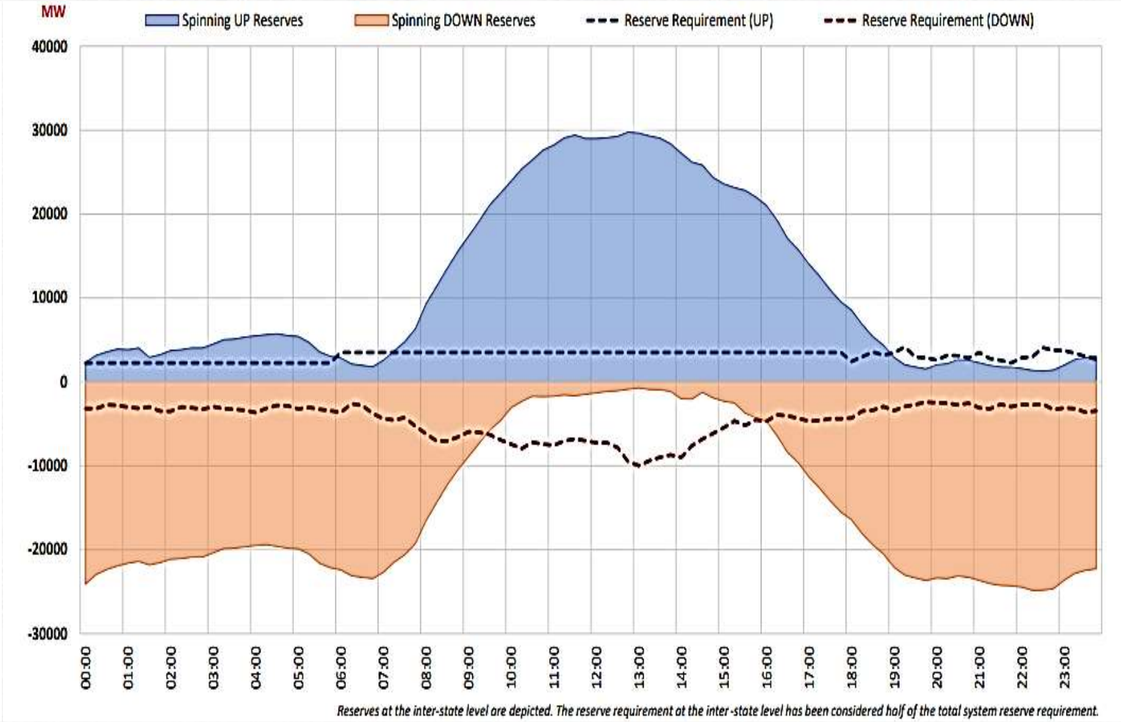
Sources: Grid-India and IEX

All India Demand Profile on 15 Aug 2025



- Need to maximize thermal to meet evening net demand
- Need for thermal to operate at min. level to balance grid during max. RE generation

All India Reserves Profile on 15 Aug 2025



- Shortfall in down reserves during solar hours
- Shortfall in up reserves during non-solar peak hours

CEA (Grid Standards) Regulations

Regulation 3(C) - Ensure that the temporary over voltage due to sudden load rejection remains within the following limits:

Nominal System Voltage (kV rms)	Phase to Neutral Voltage (kV peak)
765	914
400	514
220	283
132	170

Maximum fault clearance time is as follows:

Nominal Voltage (kV rms)	Maximum Time (milliseconds)
765 and 400	100
220 and 132	160

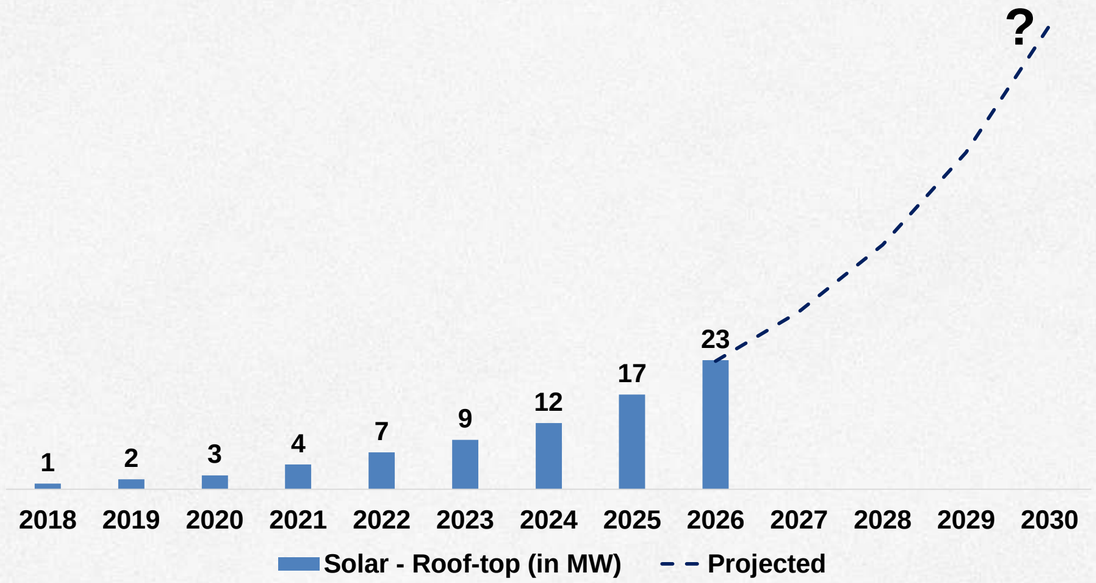
- **Adherence of the regulations shape:**
  - ❑ Fault isolation speed.
  - ❑ RE ride-through duration.
  - ❑ Tolerable voltage stress (avoid cascades)

A Sample Snapshot

Date & Location	05-May-2025 || Jaisalmer (RJ)
Initiating event	R–N (phase-to-earth) fault on 220 kV NTPC Solar – Jaisalmer line, reportedly due to snapping at Jaisalmer end
Protection action / issue	▪ Line fault escalated into a bus fault, leading to operation of 220 kV Bus-2 busbar protection. ▪ R–N fault converted into an R–Y fault, with delayed clearance ~800 ms.
Impact	Total NR solar generation drop ~1050 MW, of which ~890 MW drop was observed in Rajasthan solar.

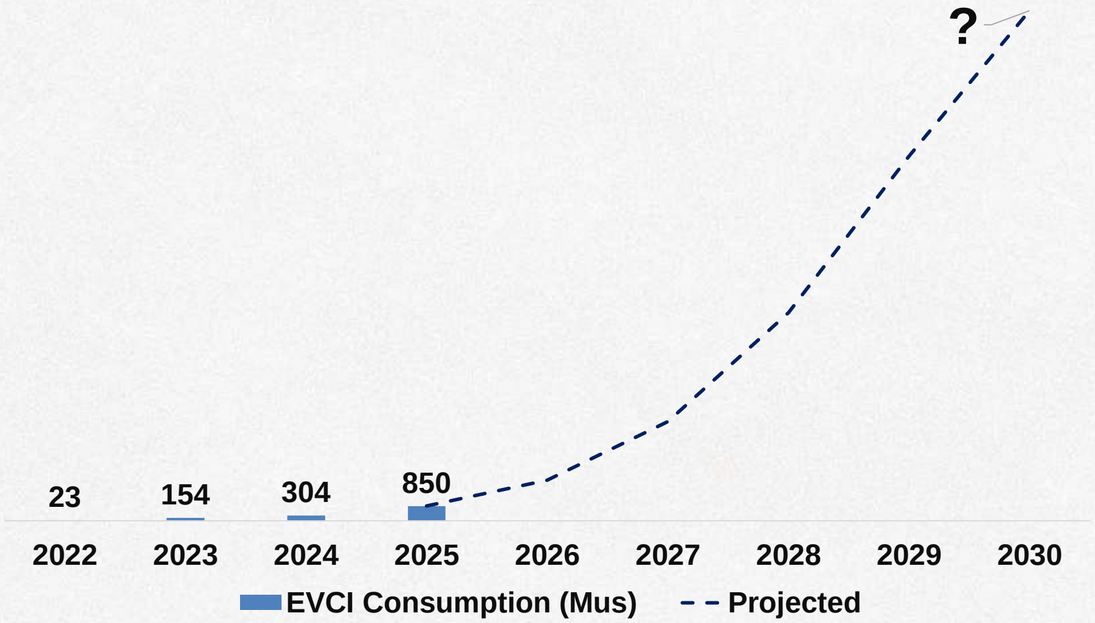
Source: CEA, and Expert Discussions

Y-o-Y Increasing Penetration of RTS



- Lack of visibility of RTS generation
- Need of readiness in other emerging areas at distribution downstream – V2G, and BESS

Y-o-Y Increasing Consumption in EVPCs

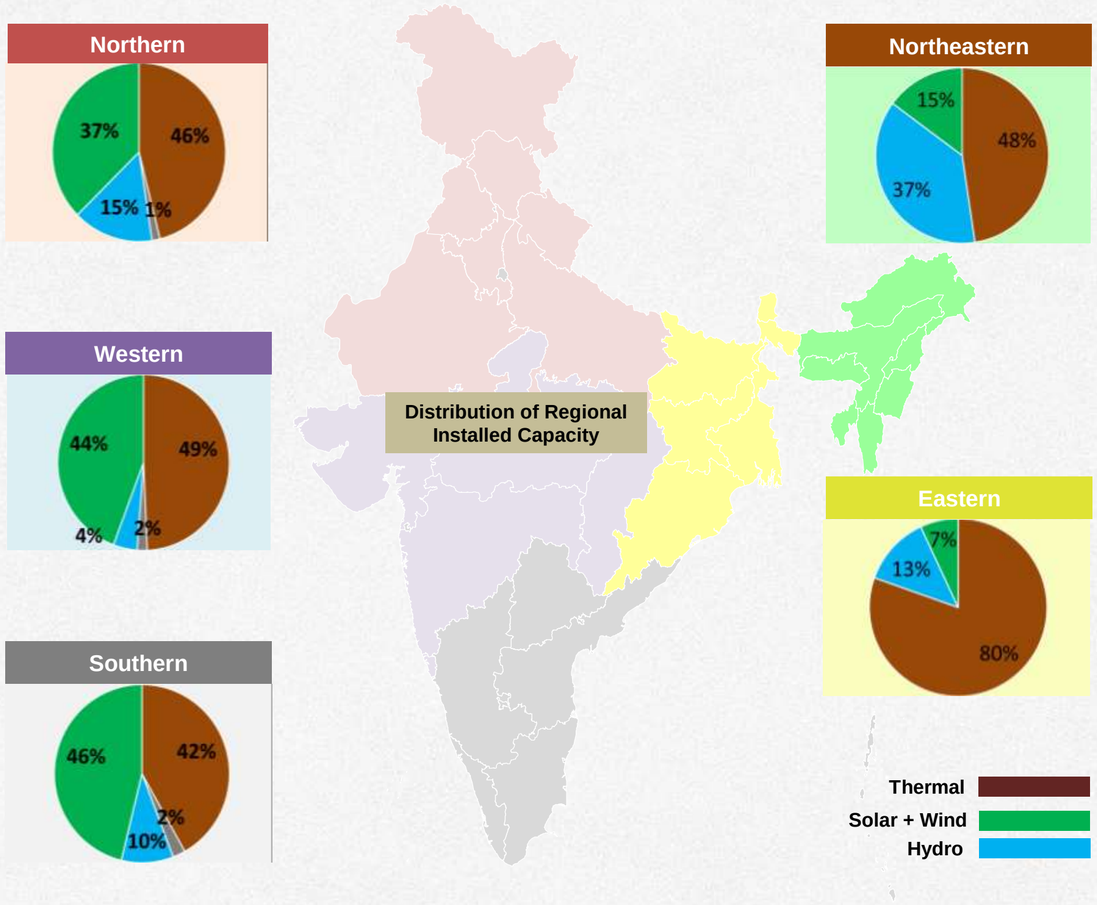


- New EVCI emerging load states - Delhi, Maharashtra, Karnataka, and UP
- EV charging: ~38 TWh by FY2031–32; ~3% of India's annual demand
- Unpredictable charging pattern

Source: CEA, MNRE, IESA

"One-size-fits-all" can be inefficient for low-RE regions

The Regional Challenge



Uniform RE obligation construct

↓ High Imports

High landed cost of electricity

↓ Limited need of ESS

Context dependent need of ESS

↓ Increasing DERs

Workforce Development Needs

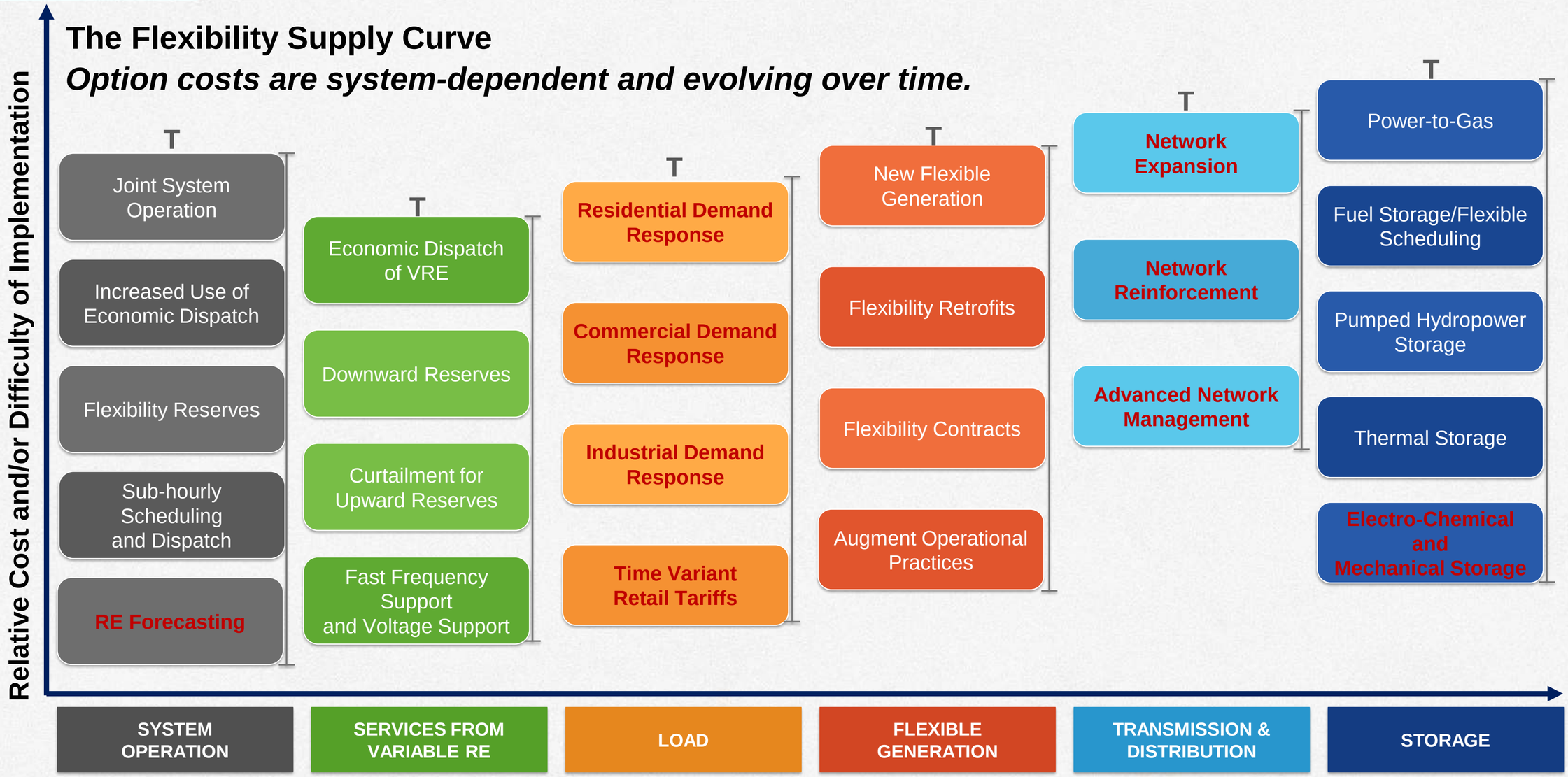
Source: CEA, , as on 31 Oct 2025

Way Forword

Least-cost RE integration requires stacking multiple flexibility options—operations, demand response, T&D, and storage

The Flexibility Supply Curve

Option costs are system-dependent and evolving over time.



Source: NREL

Key Points for Discoms

1	Enhance Visibility and Monitoring of Rooftop Solar Generation
2	Institutionalize Resource Adequacy Assessments
3	Prioritize Distributed Renewable Energy Solutions for Eastern and North-Eastern Regions
4	Plan for Grid-Forming Capabilities in High-RE and Weak-Grid Networks

Thanks