Government of India
Ministry of Power
Central Electricity Authority

Resource Adequacy: Introduction, Framework and Associated Regulations

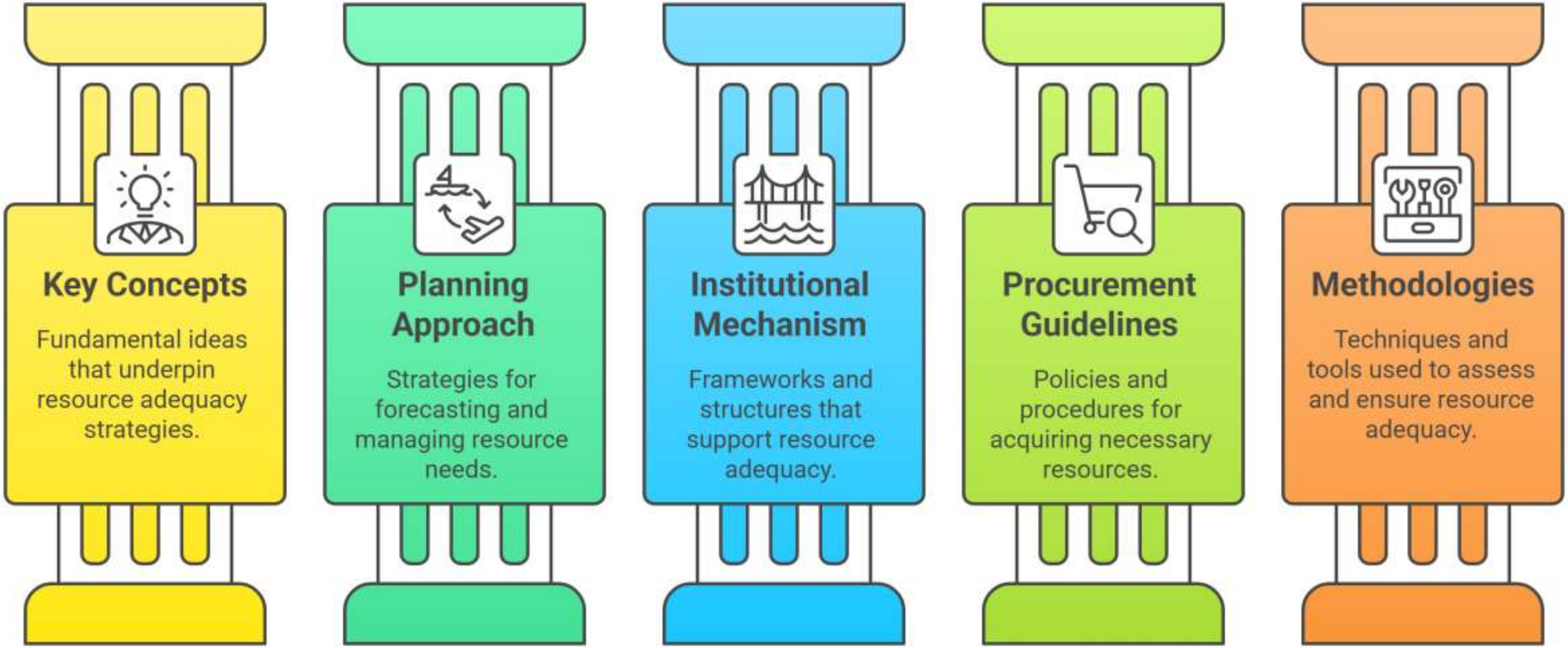
By: Apoorva Anand

Deputy Director,

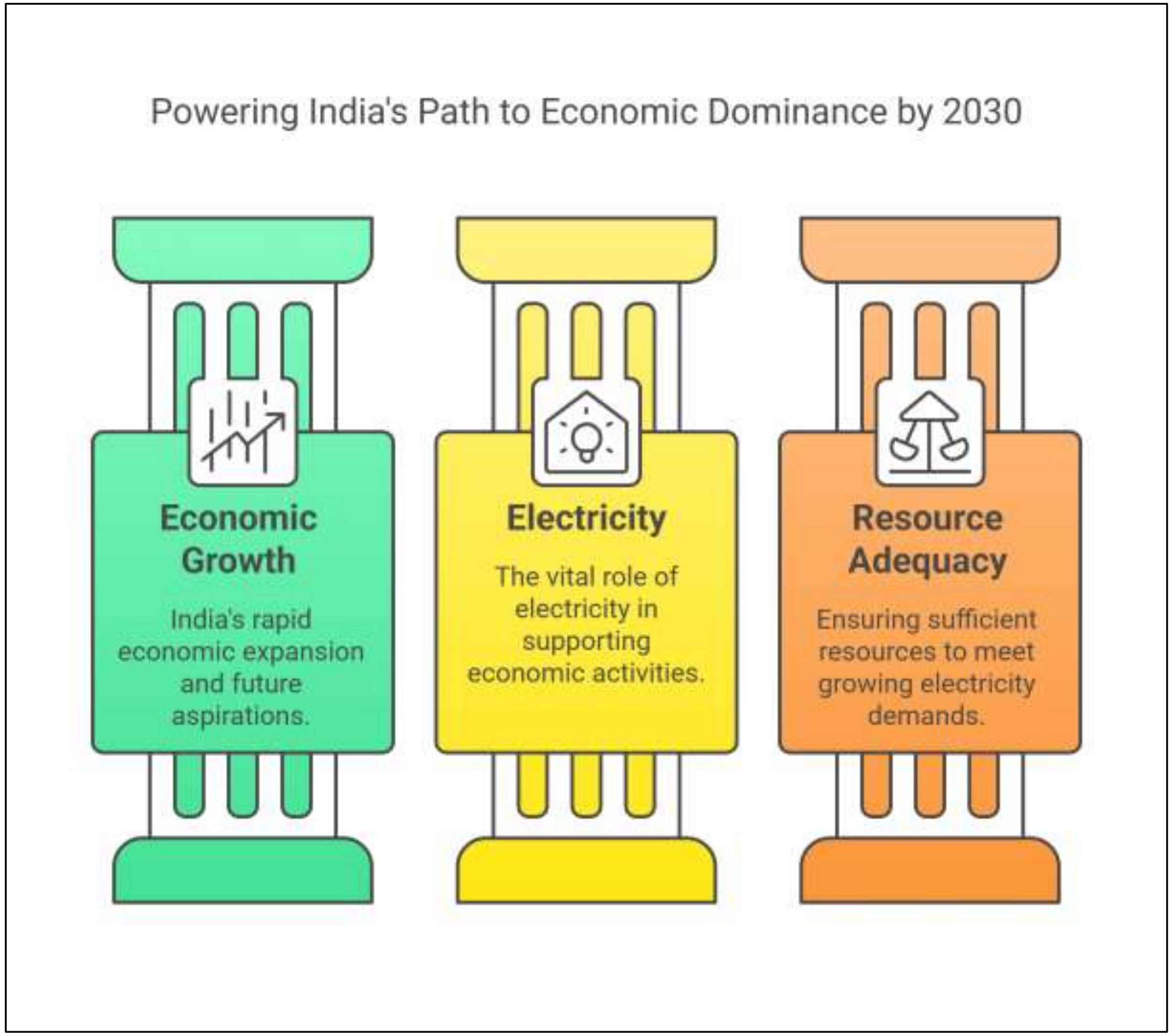
Central Electricity Authority

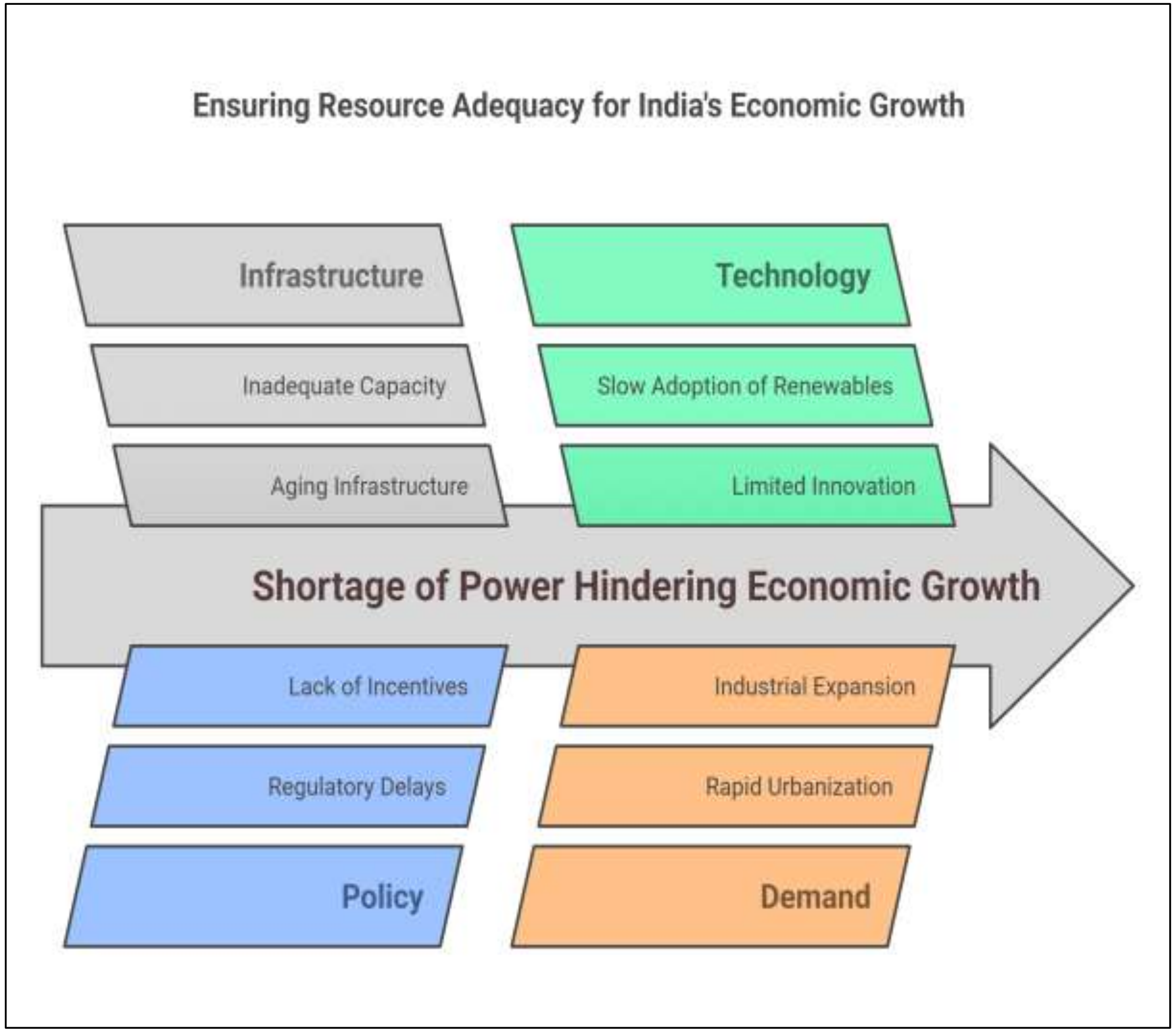
Ministry of Power

Ensuring Resource Adequacy Through Strategic Planning and Mechanisms



Background & Need



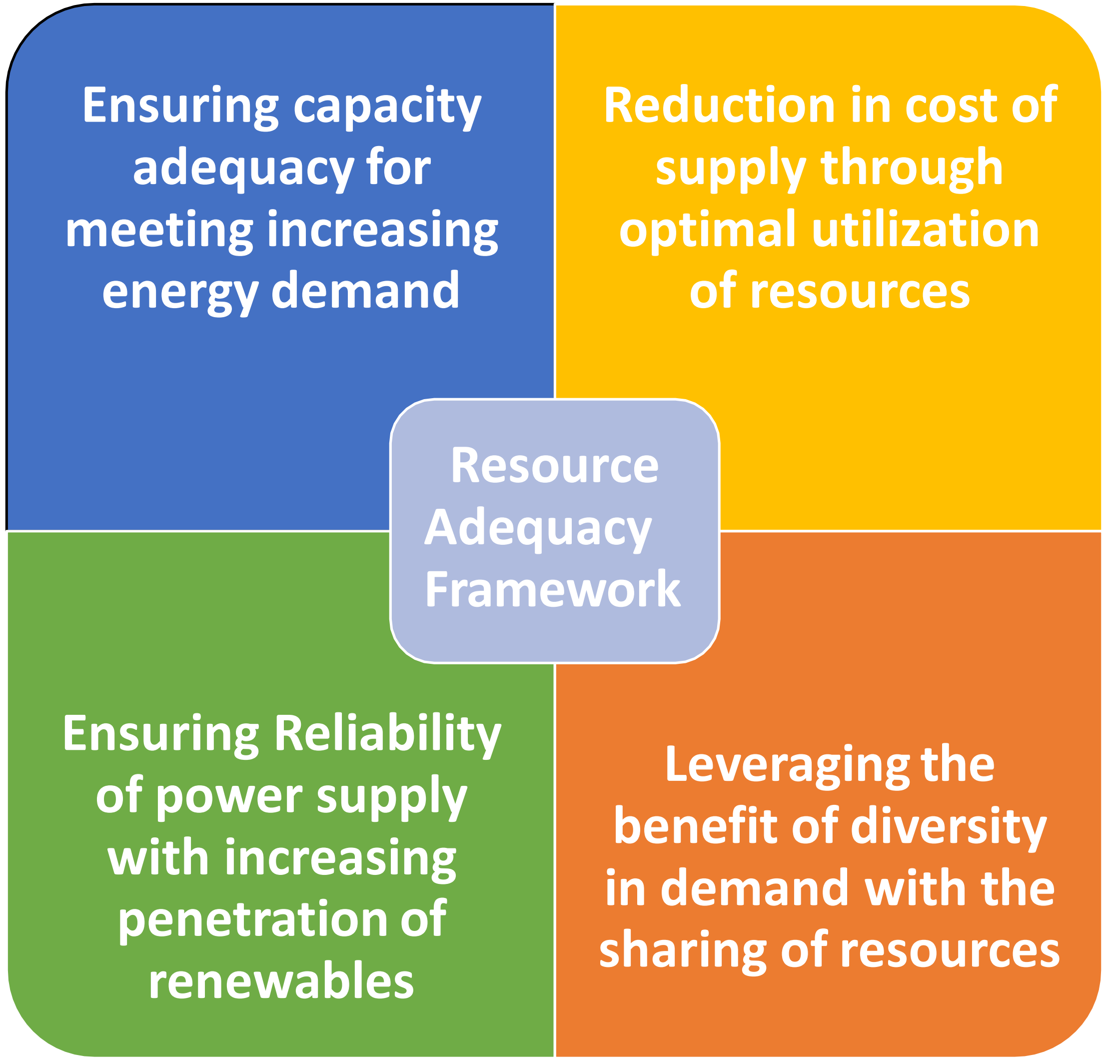


Objectives of the Framework

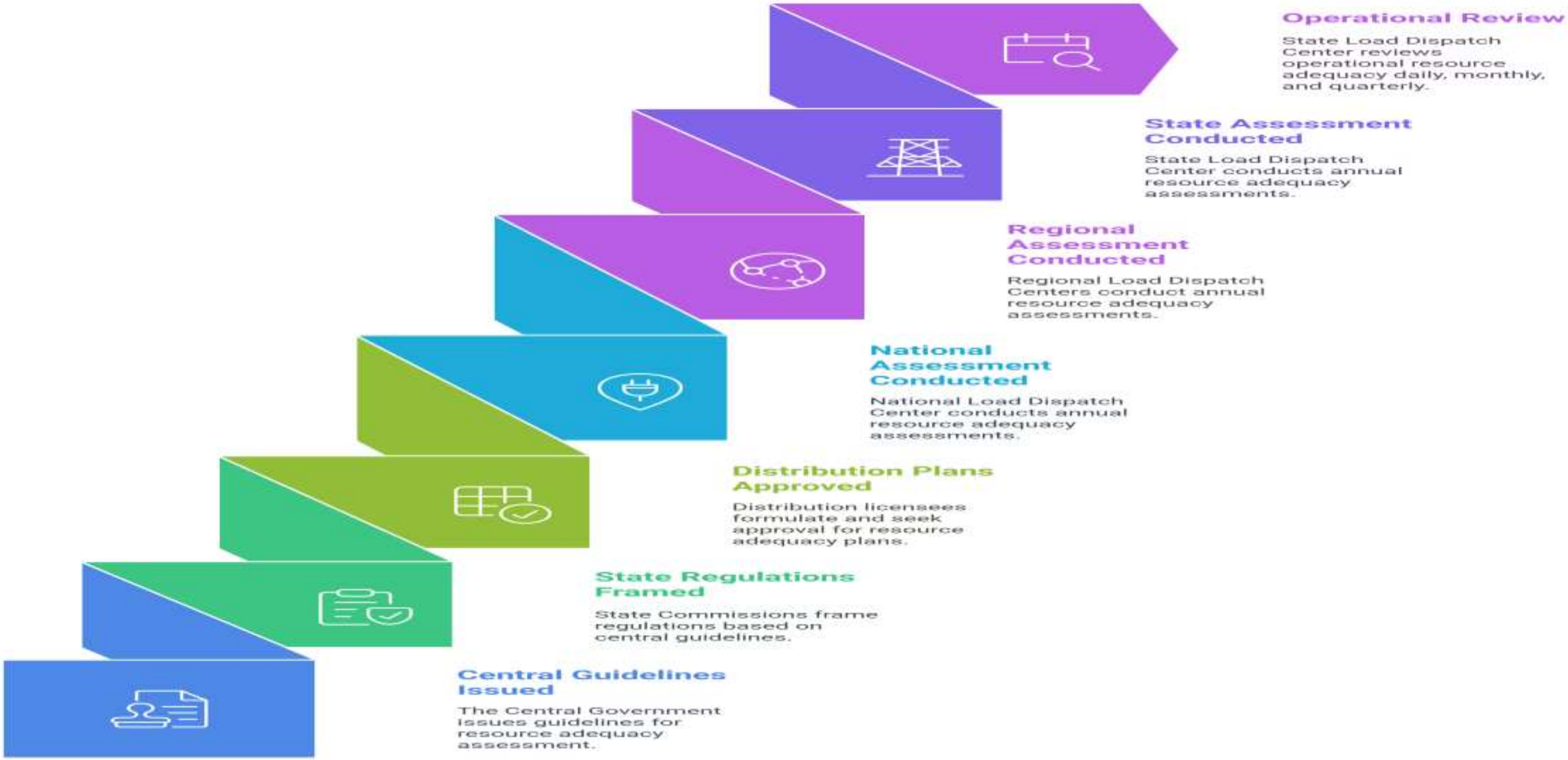
- Ensure 24x7 reliable power for all consumers.
- Mandate DISCOMs to contract sufficient capacity.
- Align power planning with climate goals (50% non-fossil capacity by 2030).

Salient Features of Resource Adequacy Framework

Benefits of Resource Adequacy Framework



Resource Adequacy Policy Framework

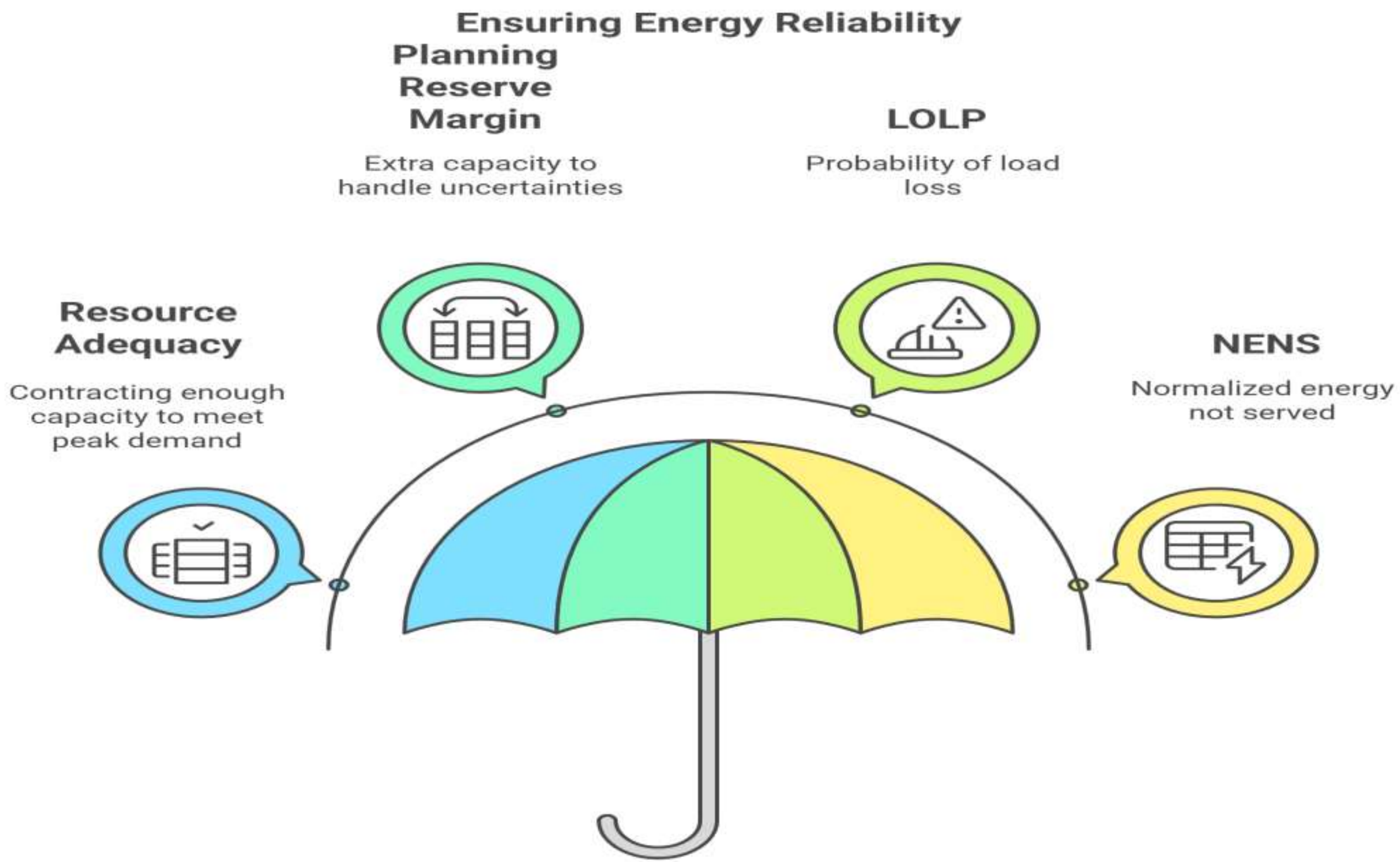


Resource Adequacy Policy Framework

- *The **State Commission** may determine **non-compliance charges** for failure to comply with the resource adequacy target approved by the Commission.*

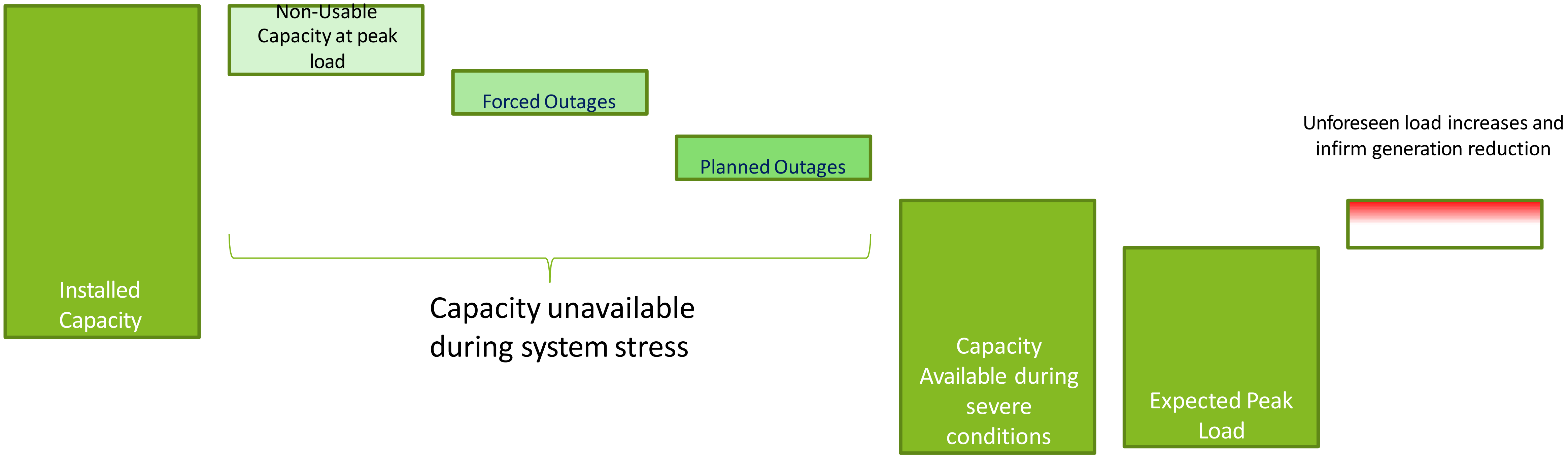
- *The **State Load Dispatch Centre** shall carry out assessments of resource adequacy, for **operational planning, at the state level,** in consultation with all the concerned stakeholders on an annual basis ,in accordance with the guidelines issued by the Central Government and the directions of the State Commission.*

- *The State Load Dispatch Centre **shall review** the **operational resource adequacy** on a daily, monthly and quarterly basis*


Ensuring Energy Reliability
Planning Reserve Margin
Extra capacity to handle uncertainties
LOLP
Probability of load loss
Resource Adequacy
Contracting enough capacity to meet peak demand
NENS
Normalized energy not served

Overview of Resource Adequacy

Resource Adequacy is the dimension of grid reliability which takes the longest view. It entails having enough resources in the power system available to the system operator to meet future load, while accounting for uncertainty in both generation and load.

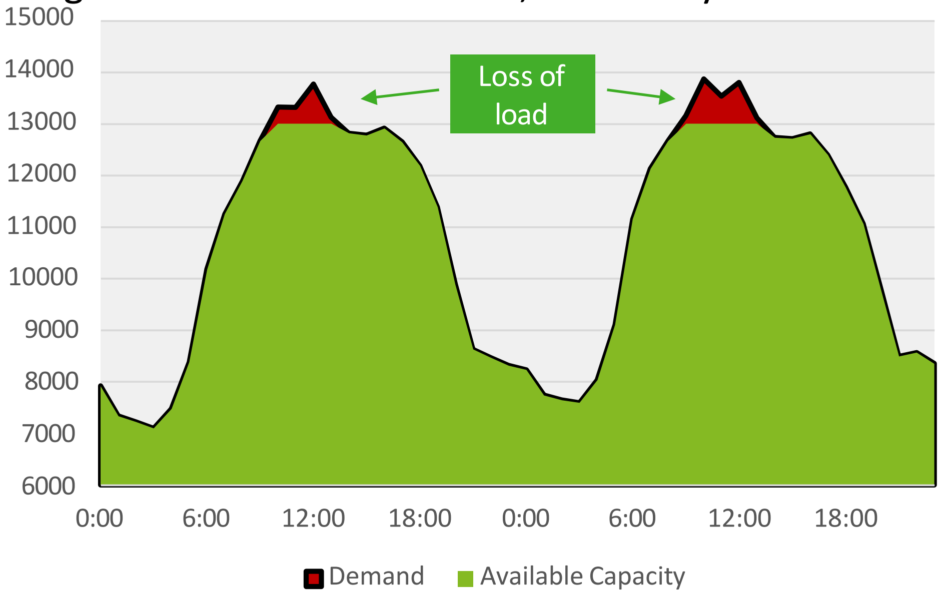


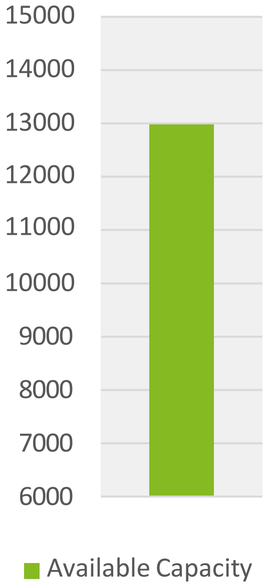
- The installed reserve margins forms the basis of resource adequacy
- The reserve margin is the amount of capacity above what is required to meet peak load

Resource Adequacy (RA)

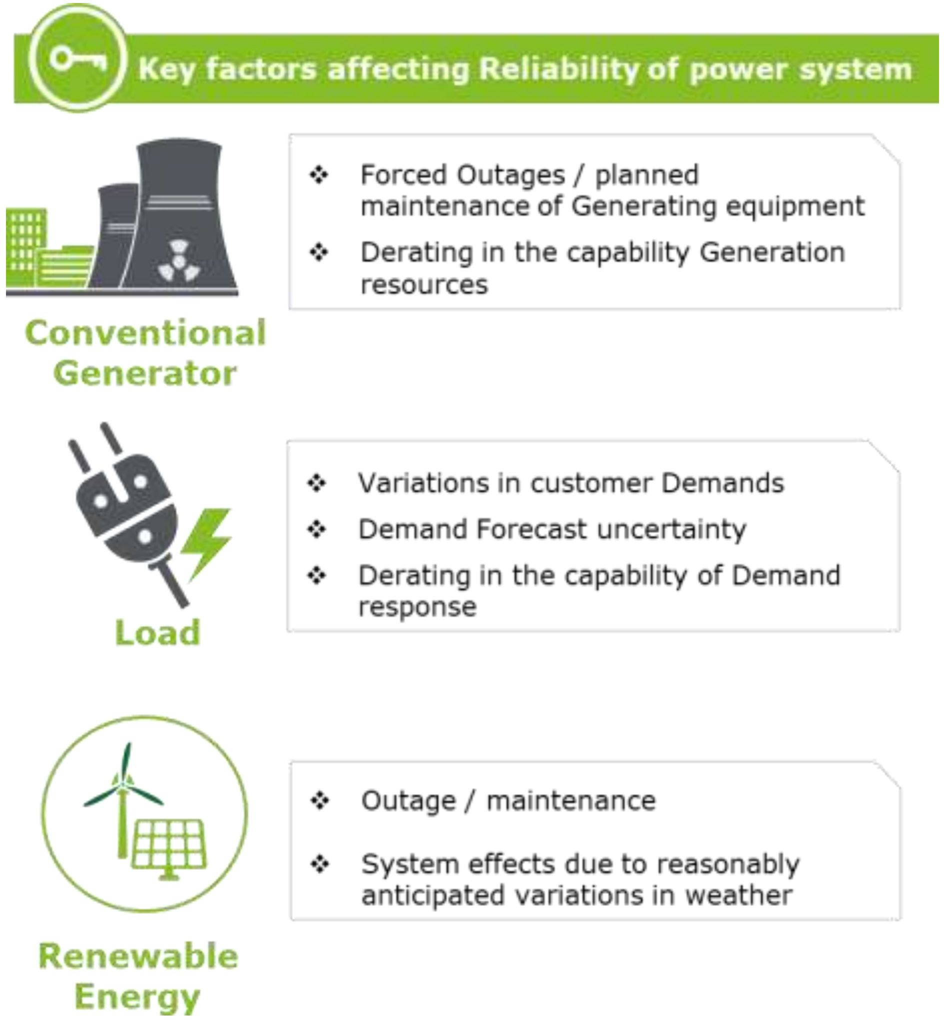
What does RA try to measure?

- Resource adequacy studies try to estimate the occurrence of Loss of Load.
- A loss of load occurs when the system load exceeds the available generation at that instance, due to any factors

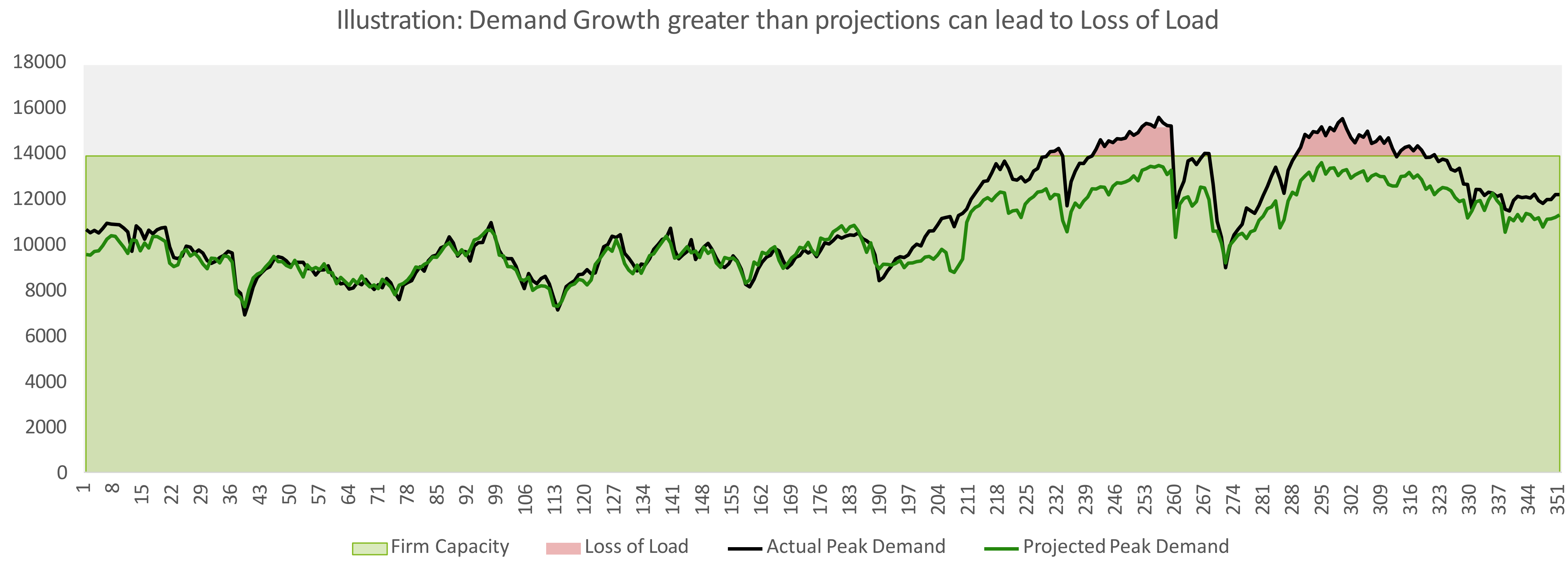




System should be able to meet demand notwithstanding scheduled and unscheduled outages of system components, variation in demand and non-dispatchable resources.

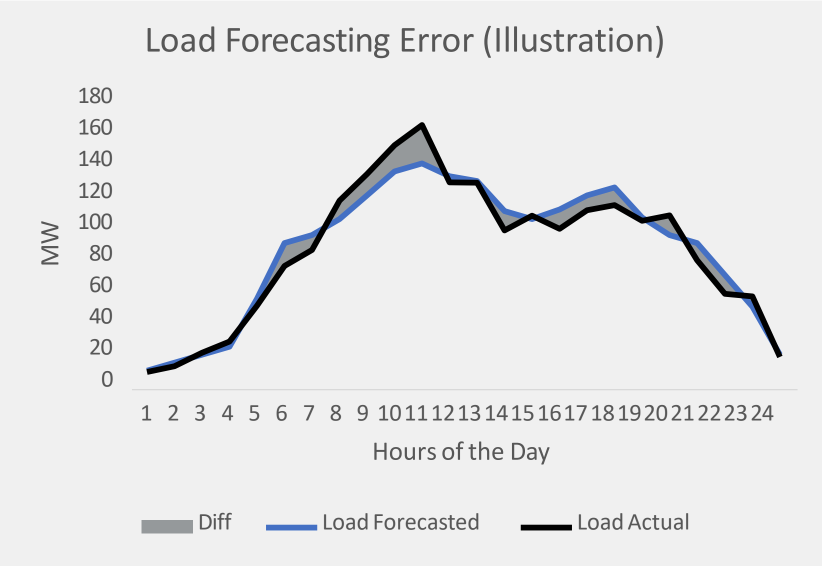


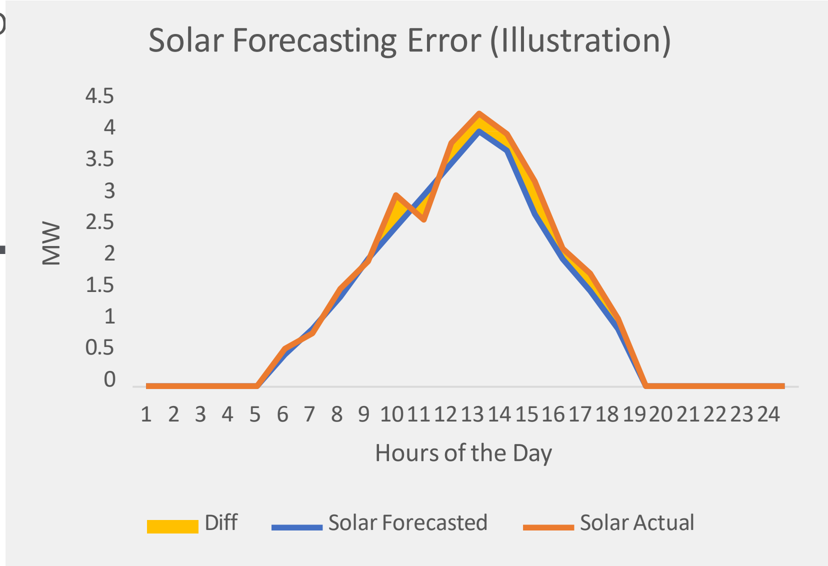
Load Volatility can cause Loss of Load

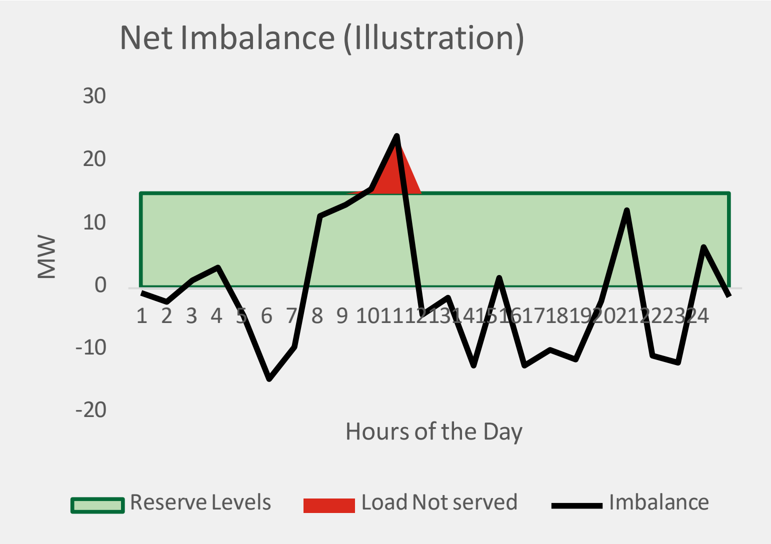


- Planning is typically done on the projected peak demand. If the demand growth is higher than projected, the planned capacity addition falls short leading to loss of load
- **An extra margin of capacity should be planned to mitigate such issues**

Resource Adequacy (RA)

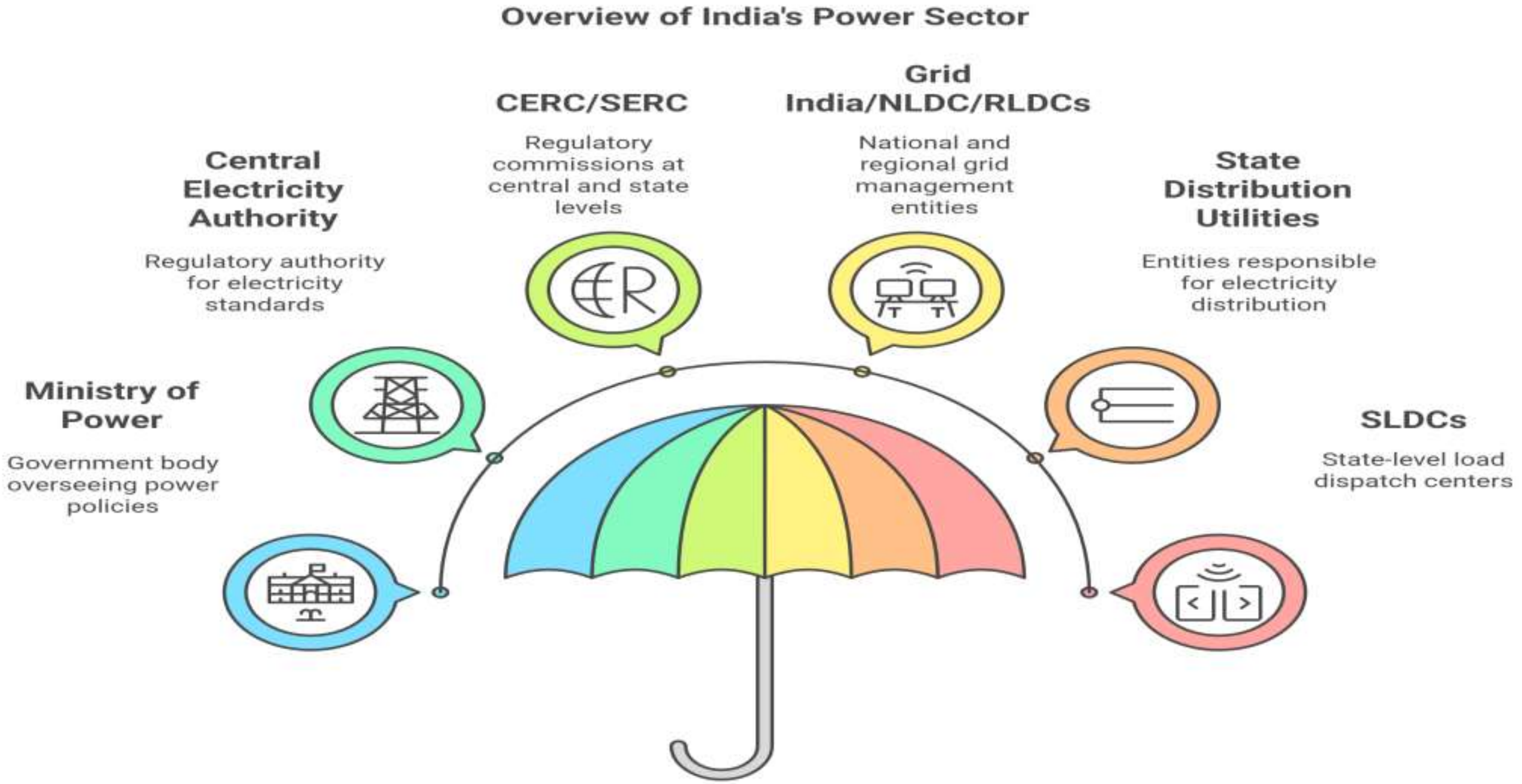




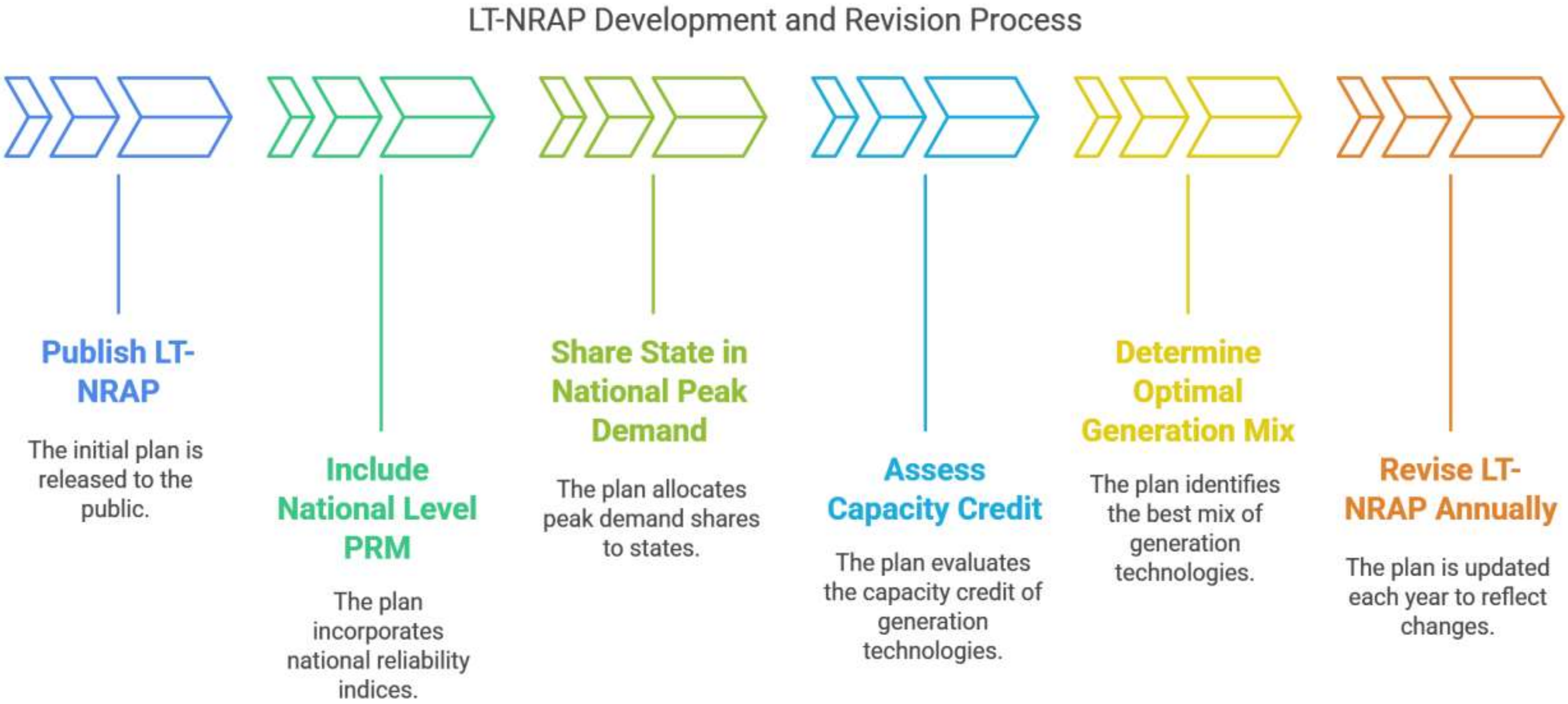


1. **System imbalance necessitates a need for flexible resources in the system.**
2. **Sufficient reserves should be deployed to meet the expected system imbalance in future.**

Resource Adequacy Stakeholders

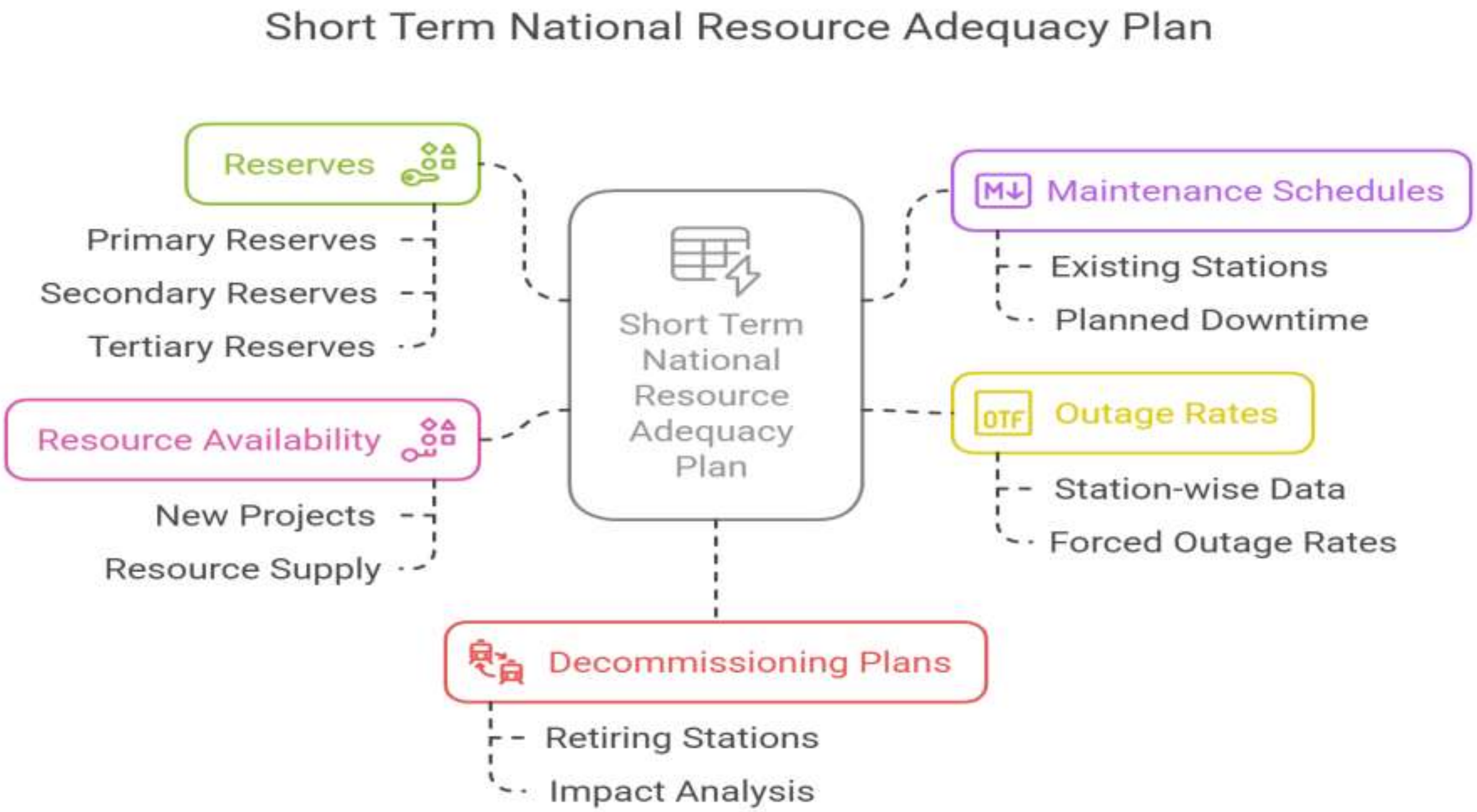


Role of CEA

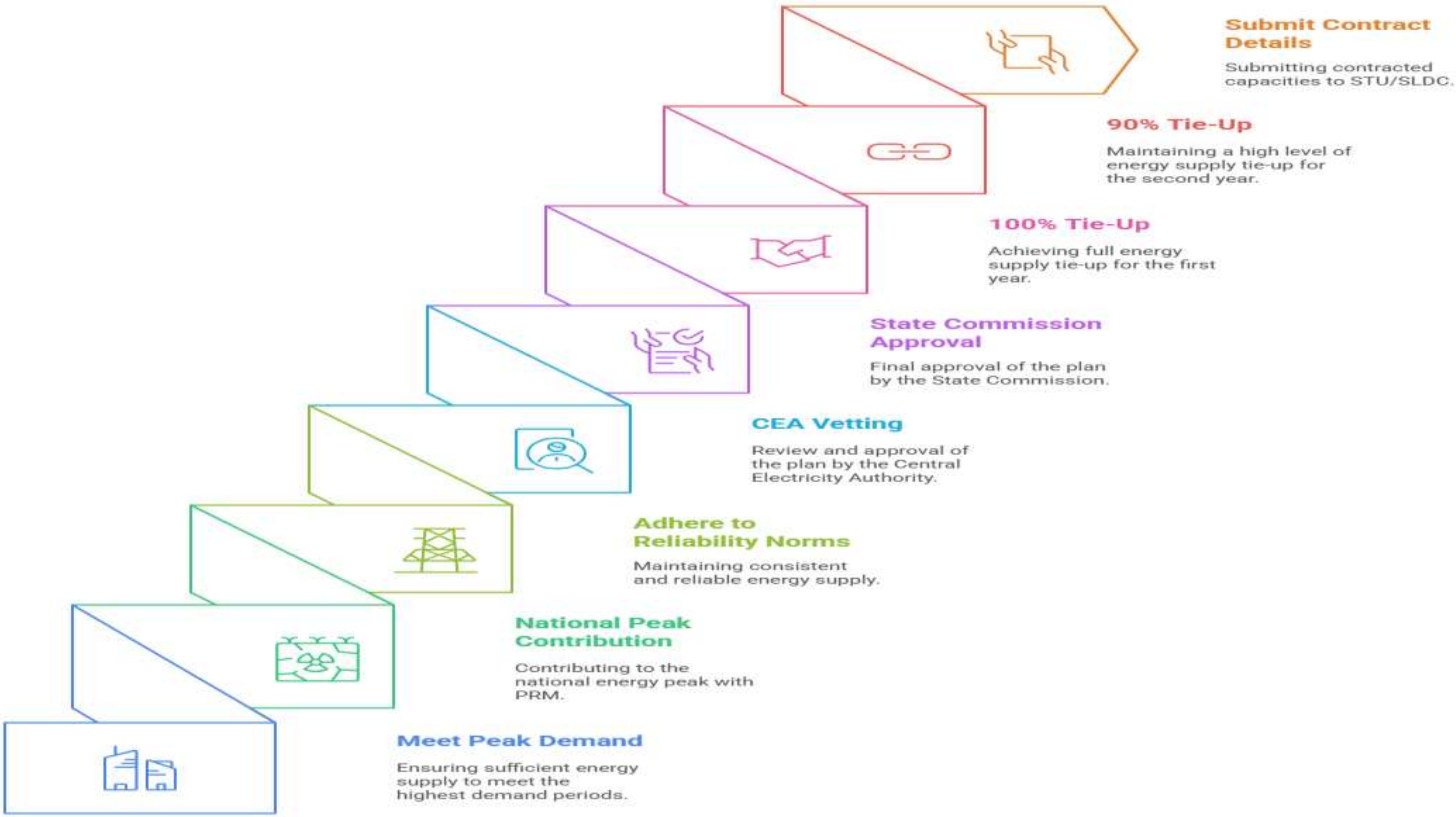


LT-NRAP Development and Revision Process
Publish LT-NRAP
The initial plan is released to the public.
Include National Level PRM
The plan incorporates national reliability indices.
Share State in National Peak Demand
The plan allocates peak demand shares to states.
Assess Capacity Credit
The plan evaluates the capacity credit of generation technologies.
Determine Optimal Generation Mix
The plan identifies the best mix of generation technologies.
Revise LT-NRAP Annually
The plan is updated each year to reflect changes.

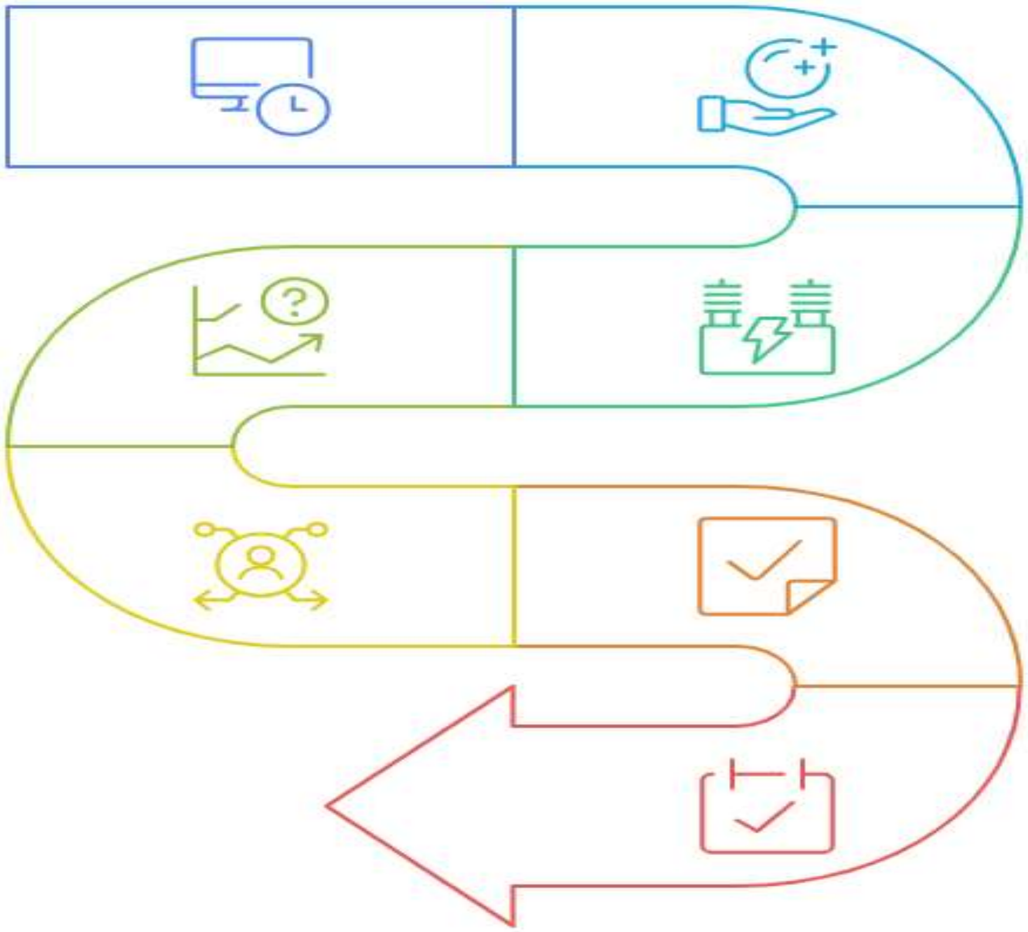
Role of NLDC


Short Term National Resource Adequacy Plan
Reserves
Primary Reserves
Secondary Reserves
Tertiary Reserves
Resource Availability
New Projects
Resource Supply
Short Term National Resource Adequacy Plan
Maintenance Schedules
Existing Stations
Planned Downtime
Outage Rates
Station-wise Data
Forced Outage Rates
Decommissioning Plans
Retiring Stations
Impact Analysis

Long term Distribution Resource Adequacy



Role of STU/SLDC



Hourly demand (15-minute time block wise)

Real-time demand monitoring

Hourly demand forecasts for the next 10 years

Long-term planning horizon

Aggregate total contracted capacities at state level

State-level capacity aggregation

Availability from existing/contracted generation resources

Resource assessment

RLDCs aggregate capacities at regional level

Regional coordination

SLDCs carry out resource adequacy assessments

State-level operational planning

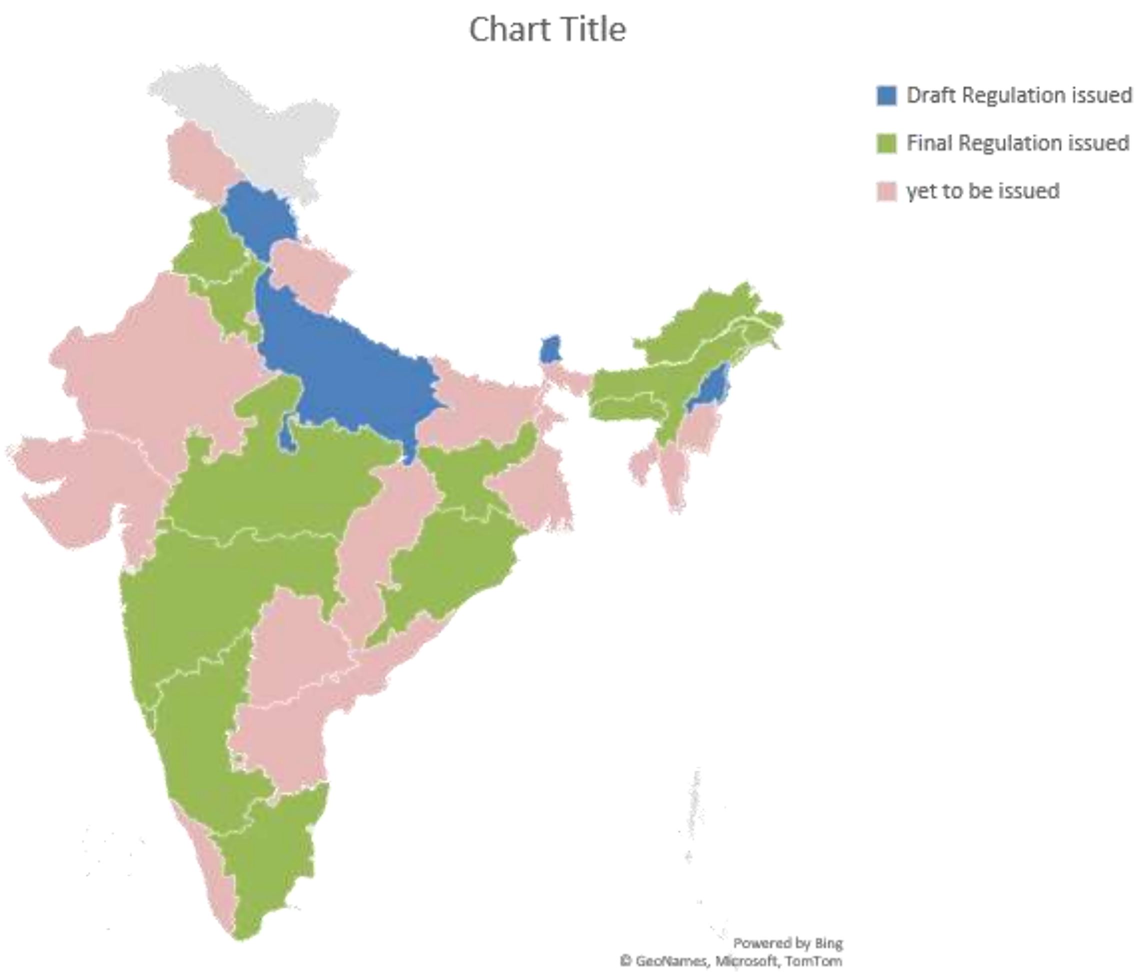
Review ST-DRAP on daily, monthly, and quarterly basis

Continuous review process

Role of SERCs

- SERCs to timely approve the LT-DRAP and contracted capacities of DISCOMs
- Monitoring/Compliance of RA by SERCs
- 12-13 SERCs issued final/Draft RA regulation till now

Status of RA Regulations by SERCs



Status of RA Regulations	SERC / JERC
Final Regulations Issued	Punjab, Meghalaya, Madhya Pradesh , Arunachal Pradesh , Karnataka, Maharashtra, Assam, Goa, Haryana, Jharkhand, Tamil Nadu, Odisha
Draft Regulations issued	Uttar Pradesh, Nagaland, Himachal Pradesh, Sikkim
Yet to be issued	Jammu & Kashmir, Uttarakhand, Delhi, Rajasthan, Gujarat, Kerala, Andhra Pradesh, Telangana, Chhattisgarh, Bihar, West Bengal, Sikkim, Assam, Manipur, Tripura, Mizoram

Resource Adequacy Guidelines Framework

Entity	Description	May'xx	Jun'xx	Jul'xx	Aug'xx	Sep 'xx	Oct'xx	Nov'xx	Dec'xx	Jan'(xx+1)	Feb'(xx+1)	Mar'(xx+1)	Delivery Period (Apr'(xx+1) - Mar'(xx+2))
STU/SLDC	STU/SLDC, on behalf of distrubution licensees shall provide to CEA and NLDC the details regarding demand forecasts for the next 5 years, assessment of exisiting generation resources and other details required for LT-NRAP and ST-NRAP	■											
CEA	To publish LT-NRAP containing National PRM, Reliabillity Metrics, Coincident peak, capacity credits and Optimal Generation mix for 10 years horizon.		■	■									
NLDC	To publish ST-NRAP.		■	■									
Discoms	LT-DRAP exercise for long term horizon(10 years) which is RA compliant as per coincident peak to be submitted to CEA				■	■							
CEA	Vetting of discom's contracting plan for coincident peak contribution and to meet their own energy and peak						■	■					
SERC	SERC to approve of discom's contracting plan for coincident peak contribution and to meet their own energy and peak								■				
Discoms	To contract capacities as per approved plans.									■			
	Submit contract capacities to STU/SLDC									■			
STU/SLDC	STU/SLDC to submit state-level aggregated capacities to RLDC										■		
RLDC	RLDC submit regional-level aggregated capacities to national level										■		
POSOCO/NLDC	POSOCO/NLDS to check RA compliance at national level											■	
	Any Shortfall shall be communicated to the SERC for comliance or is balanced through a national level auction mechanism											■	

IEGC on Resource Adequacy

❖ Chapter 2 of Central Electricity Regulatory Commission (Indian Electricity Grid Code) Regulations, 2023 talks about Resource Planning Code.

❖ **Core Components:**

❑ **Integrated Resource Planning (IRP):**

- Encompasses demand forecasting, generation resource adequacy planning, and transmission resource adequacy assessment.
- Aims to meet projected demand reliably, adhering to reliability standards, and optimizing the generation mix with a focus on integrating renewable energy.

IEGC on Resource Adequacy

❑ **Demand Forecasting:**

- Distribution licensees must estimate demand across long-term, medium-term, and short-term horizons.
- Utilizes various forecasting methods (trend, time series, econometric, etc.) and includes detailed daily load curves.
- State Transmission Utilities (STUs) consolidate licensee forecasts for state-wide demand estimations.
- The Forum of Regulators (FOR) may provide guidelines for consistency and accuracy.

IEGC on Resource Adequacy

Generation Resource Adequacy Planning:

Licensees assess existing resources and identify additional requirements to meet forecasted demand.

Develop generation resource procurement plans, considering both state and regional resources.

- Ensure adequate resources and maintain a planning reserve margin (PRM) as specified by the Central Electricity Authority (CEA).
- Prioritize optimal and least-cost procurement, considering peak demand, seasonal needs, and potential for inter-state capacity sharing.
- The National Load Dispatch Centre (NLDC) conducts simulations to aid states in optimal generation resource planning.

Distribution licensees are responsible for final procurement decisions and must demonstrate resource

adequacy, facing penalties for non-compliance.

FOR may develop model regulations for standardized assessment and procurement.

Judicious mix of Long, Medium and Short-Term Contracts

Type of Contract	Meeting Distribution Licensee Contribution in national Peak	Distribution licensee own peak and electricity requirement
Long-Term	75-80%	>75%
Medium-Term	10-20%	10-20%
Short-Term	0-15*%	0-15%

* Power procurement through the power exchanges, such as the Day-Ahead Market segment, shall not be considered

Challenges and Opportunities

- Challenges: Data granularity, state-level modeling capacity, regulatory compliance.
- Opportunities: Grid modernization, storage integration, investment signals.

Role of Central Electricity Authority Under Resource Adequacy Framework

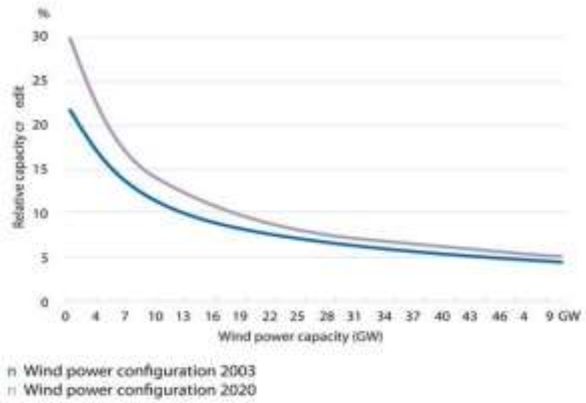
CENTRAL ELECTRICITY AUTHORITY

Publish Long-term National Resource Adequacy Plan (LT-NRAP), which shall determine the optimal Planning Reserve Margin (PRM) requirement at the All-India level, conforming to the reliable supply targets(section 3.1)

Publish the capacity credits for different resource types on a regional basis. (Section 3.1)

Specify the State/UT's contribution towards national peak. (Section 3.1)

Publish the national-level PRM as a guidance for all the States/UTs to consider while undertaking their RA exercises. (section3.1)



Methodology for
Capacity Credit of Generation Resources
&
Coincident Peak Requirement of Utilities
under
Resource Adequacy Framework




Coincident Peak

What is Coincident Peak?

- Contribution of State/UT or Distribution Utilities during National Peak
- Top 5% of National Peak instead of Single Peak
- May or May not be same as own peak of State/UT

Resource Adequacy framework

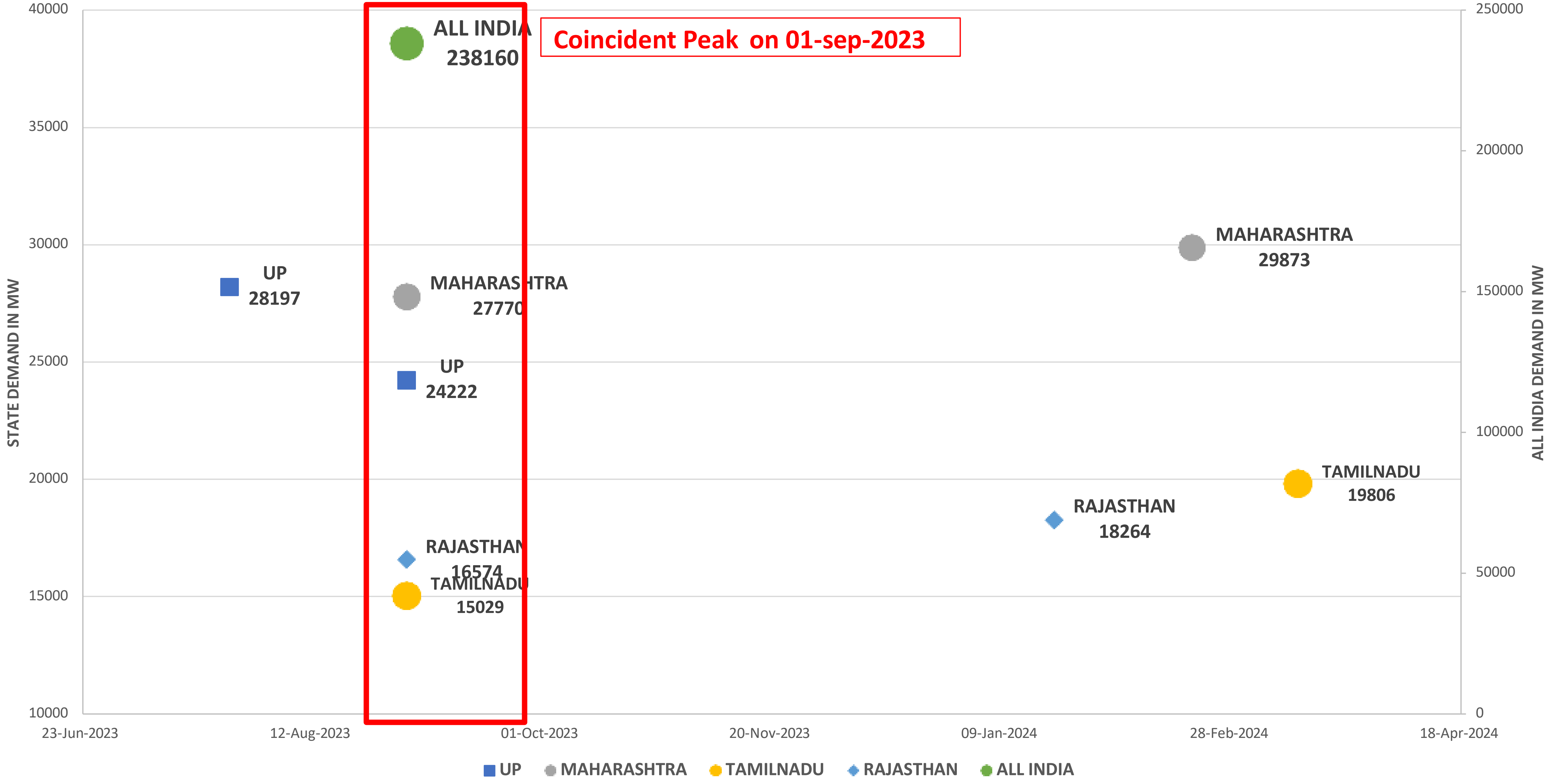
- The utilities must ensure sufficient tied-up capacity from long-term, medium-term, and short-term (Bilateral only) as per their contribution to National Peak demand +PRM
- Share of Capacity tie-up

  Long term- 75-80%

  Medium-term- 10-20%

  Short-term- 5-10%
- 100% tie-up for the first year and a minimum 90% tie-up for the second year to meet the requirement of their contribution towards meeting national peak to SERCs/JERCs

Coinicident Peak vs Own Peak(FY 2023-24)



Methodology for Calculation of Coincident Peak

- **Top 5% methodology**
  - ➢ Average State/Distribution Utilities Demand During the Top 5% of National Demand.
- **PROS:**
  - ➢ Easier to calculate.
- **CONS:**
  - ➢ Doesn't take into account time of day(Solar ,Non-Solar).
  - ➢ Average value may not be adequate during high-demand hours.
  - ➢ States with Solar Capacity tied up may face challenges in meeting their coincident peak demand during Non-Solar Hours

Solar vs. NonSolar Hours

- ➢ Top 5 % of demand during Solar and Non-Solar Hours.
- ➢ 80th percentile Instead of Maximum

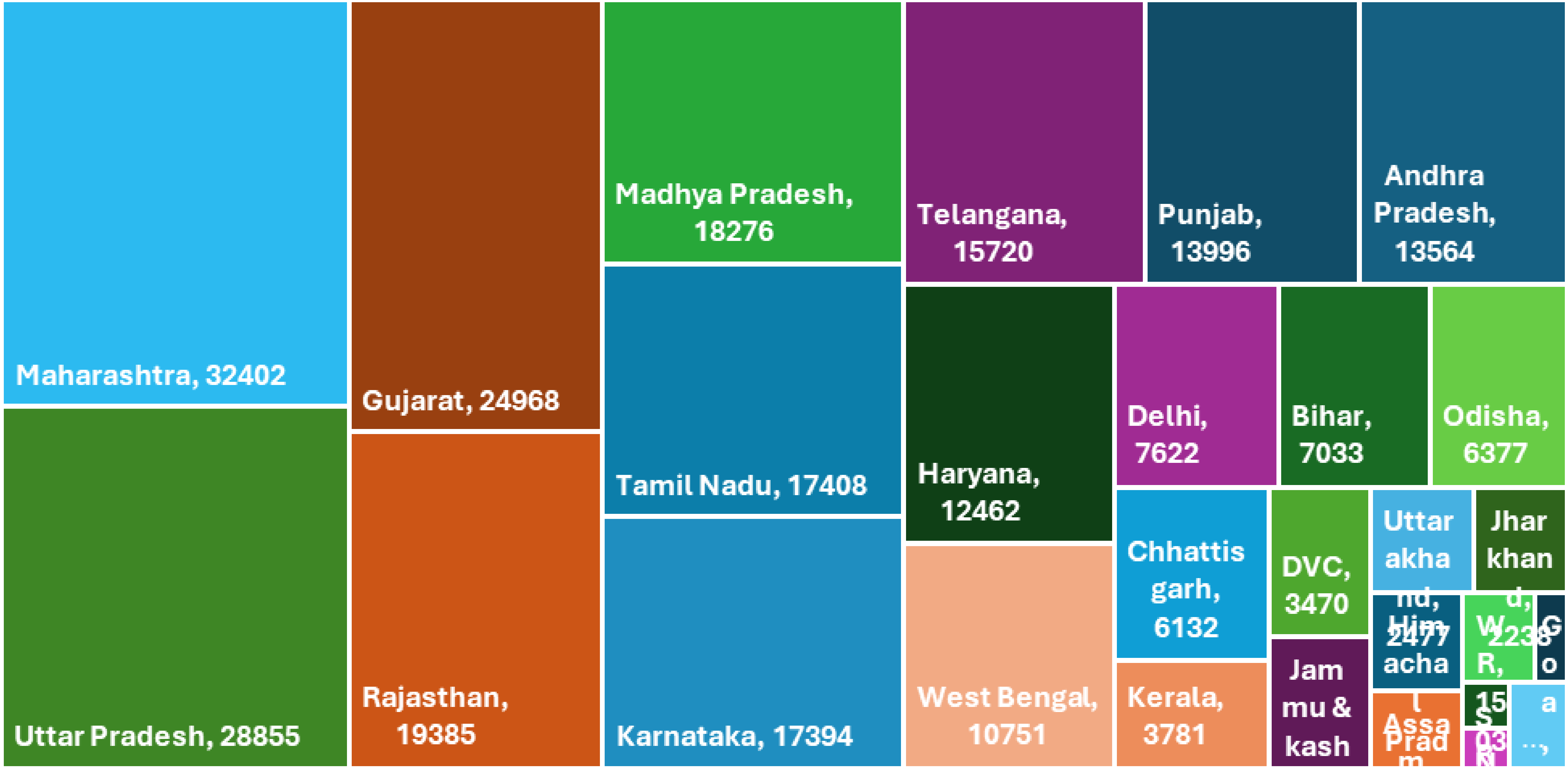
PROS:

- ➢ Impact of Solar, Non-Solar hours considered
- ➢ Different Coincident Peak requirements for Solar and Non-Solar Hours

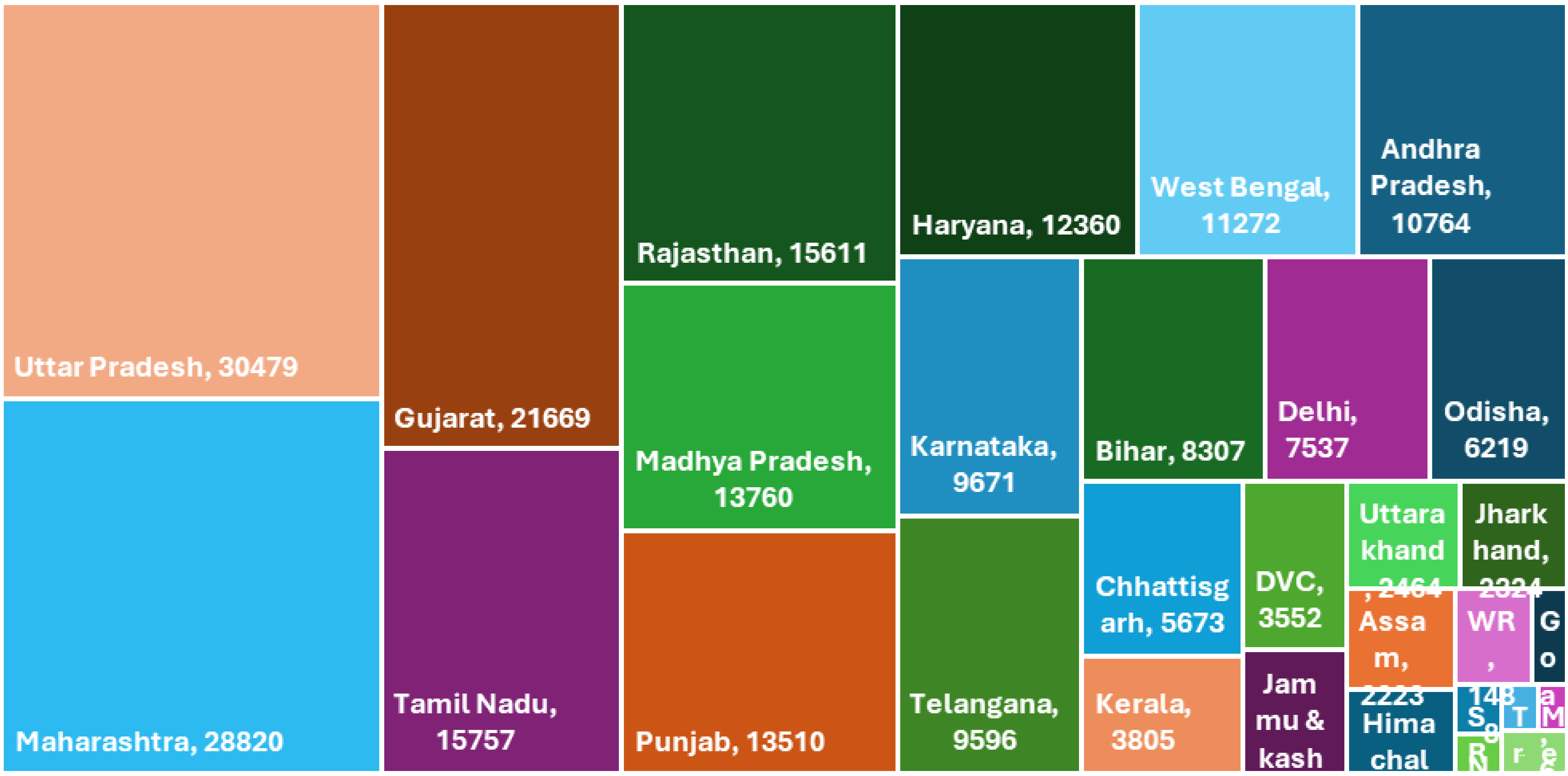
CONS:

- ➢ States with higher coincident peak demand during non-solar periods compared to solar periods may need to acquire additional conventional power capacity (like coal or gas) to meet their resource adequacy requirements

2025-26 Solar coinicident peak



2025-26 Non Solar Coincident Peak



Capacity Credit

What is Capacity Credit?

- Capacity Credit refers to firm capacity available during peak demand period.
- Capacity Credit of Conventional Sources is based on availability.
- Capacity Credit of VRE Sources is calculated using Statistical analysis.

Resource Adequacy framework

At National Level

∑ Source wise Installed capacity (ALL INDIA) * Capacity Credit of the source= National Peak Demand *(1+National PRM)

For Distribution Licenses

∑ Source wise tied up capacity (Distribution licensee) * Capacity Credit of the source= Contribution to National Peak *(1+National PRM)

Methodology for calculation of Capacity Credit for VRE Sources

Top 10% Demand methodology

- Median of VRE Profile during Top 10% demand Hours.
- Easier to calculate
- Doesn't take into account time of day(Solar ,Non Solar).

Solar Vs Non-Solar Hours

- Top 5 % of demand during Solar and Non-Solar Hours.
- Median of Profile during Top 10% demand Hours
- Variation of Wind CC during Solar vs non-Solar Hours

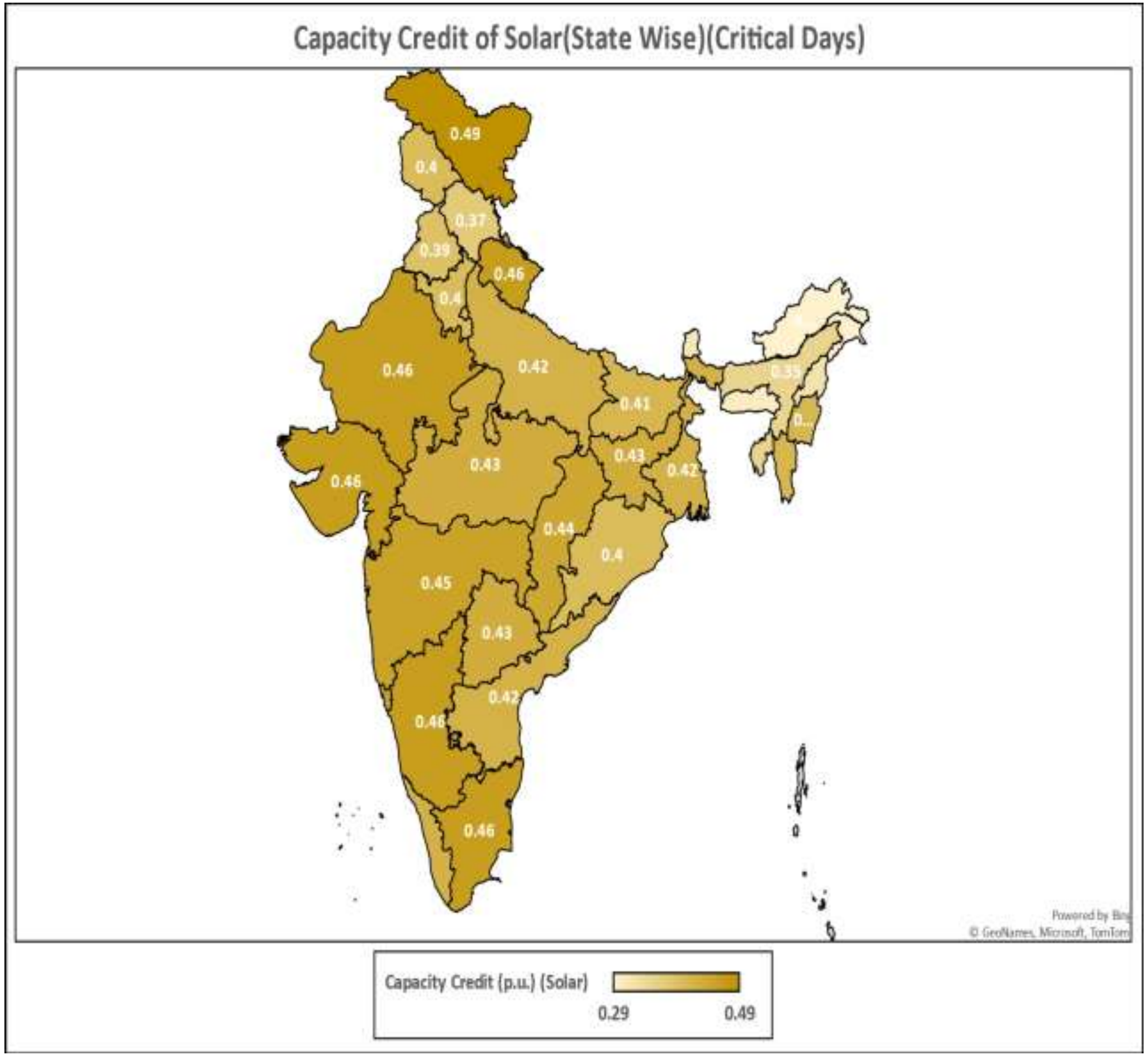
Critical Day Analysis

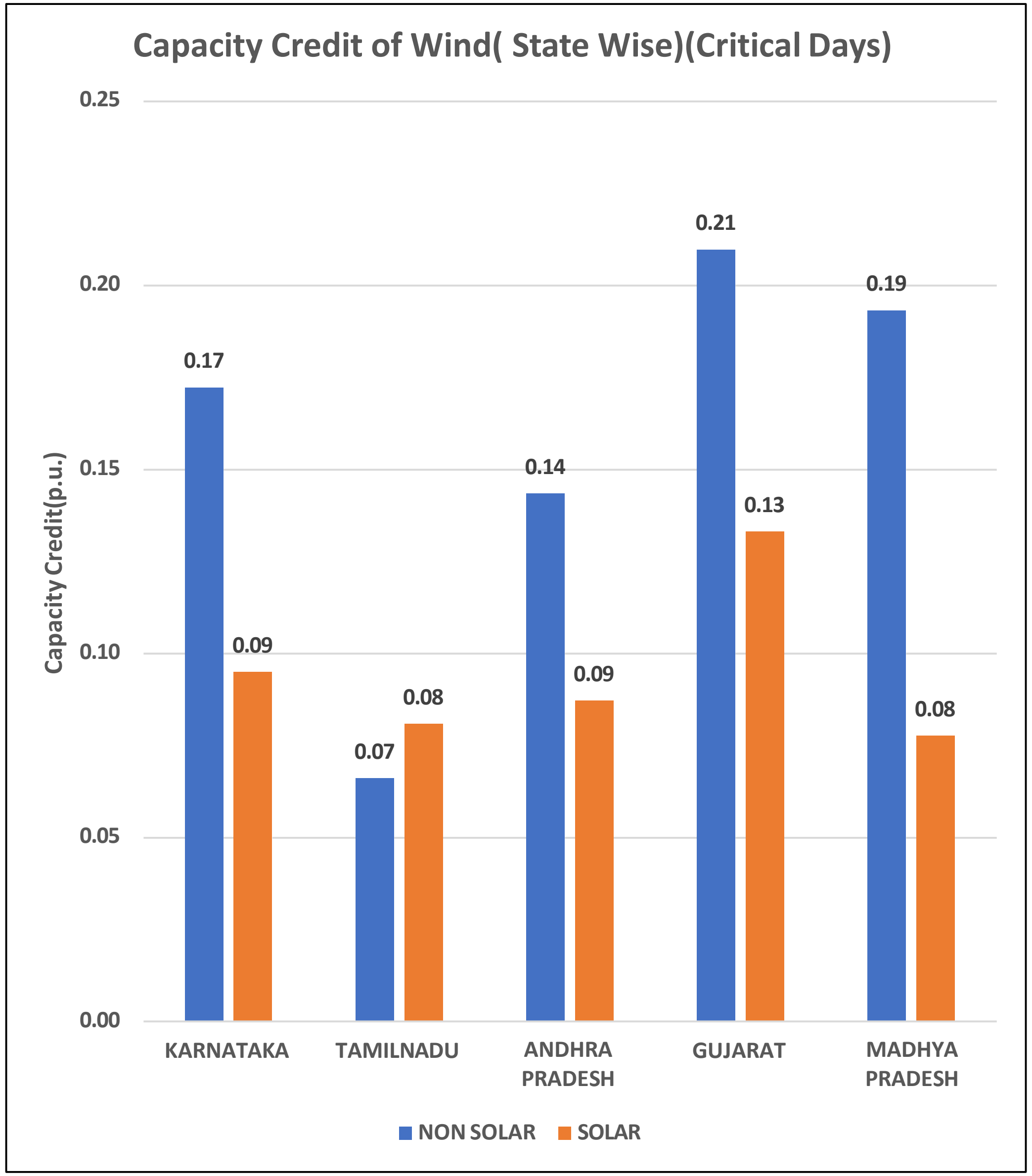
- Critical days instead of Critical blocks
- Both Demand & RE generation instead of only high Demand period
- High Demand- Low RE, Medium Demand-LOW RE days
- K means clustering algorithm
- Computationally complex

Capacity Credit using Critical days analysis

HIGH RE-Low Demand	High RE-Medium Demand	High RE-High Demand
Medium RE-Low Demand	Medium RE-Medium Demand	Medium RE-High Demand
Low RE-Low Demand	Low RE-Medium Demand	Low RE- High Demand

Capacity Credit of VRE Sources(Critical Days)





Modelling Methodology

Input data assumptions

Demand and energy forecast , Load profile, retirements, etc.

Existing resources data

Unit capacity, auxiliary consumption, fuel type & cost, heat rate, outage rate, availability profile, O&M cost , Hourly Solar and Wind generation profile, etc.

(Generation expansion planning software)

New resources data

Capital cost, fixed O&M cost, year of availability, availability profile, fuel type & cost, heat rate, etc.

Optimisation constraints

Plant availability, start up and dynamic characteristics, Ramp rates, fuel constraints etc.

Optimized resource plan

Long Term Planning:-Total system cost, annual system capacity requirement fuel wise.

Short term planning:-Hourly economic dispatch to meet the hourly demand

Optimization Model Framework

INPUT DATA

Plant characteristics (including storage)

- Existing generation and storage facilities
- Technology-specific operational parameters:
  - Technical Minimum
  - Ramp-up and ramp-down rates
  - Minimum up and down times
  - Battery specific (ex. DoD, Degradation)
- Commissioning and retirement timelines
- Operating costs:
  - Variable Operation & Maintenance
  - Fixed Operation & Maintenance
- Availability factors
- Emission characteristics

Demand and Peak Load

- Zonal hourly electricity demand
- Regional load factors
- Demand response parameters
- Ancillary service requirements

Reliability Simulations

Accounting uncertainty in:
- Demand forecasts
- Renewable energy generation profiles
- Hydro generation limits
- Thermal plant availability

Emissions

- Carbon costs
- Emission limits

Renewable Energy Data

- Inventory of renewable energy technologies (solar, wind, ROR, etc.)
- Installed RE capacity by zone
- Zonal hourly RE generation profiles
- Zonal RE potential (technical/assessed potential)

Plant and Network Expansion Data

- (CAPEX) requirements for generation, storage and transmission assets
- CAPEX trajectories for technologies
- Weighted Average Cost of Capital (WACC)
- Capital recovery Factor (CRF)

OPTIMIZATION FRAMEWORK

STELLAR

Strategic Expansion for Long-Term Load Adequacy and Resilience

- LP formulation
- CPLEX Solver
- CAPACITY EXPANSION PLANNING AND UNIT COMMITMENT
- INTRA & INTER-STATE TRANSMISSION EXPANSION PLANNING
- CO-OPTIMIZAITON OF ENERGY AND ANCILLARY SERVICES
- INTEGRATED DEMAND RESPONSE

TYPICAL OUTPUTS

- Capacity expansion plan
- Energy mix projections for future years
- Chronological demand-supply curves for future years
- Generation dispatch schedules for all plants
- Transmission system augmentations
- Projected transmission flows
- Disaggregated cost components
  - Operational costs
  - Balancing costs
  - Capital investment costs
- Projected electricity prices
- Projected CUF of fuels and plants
- Emission projections
- Reliability metrics:
  - LOLP
  - NENS

USES

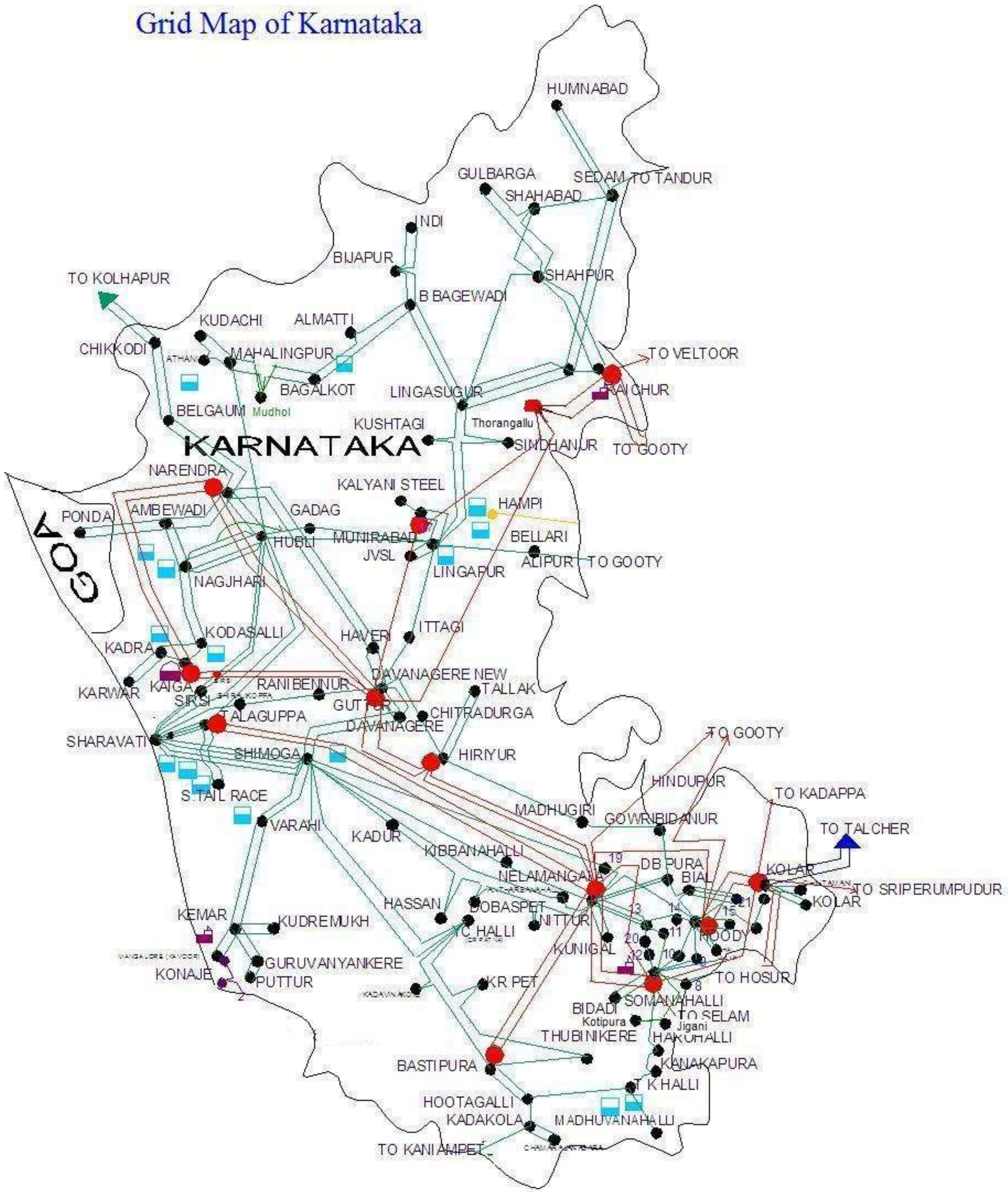
- Pathways for achieving renewable energy (RE) targets
- Resource adequacy evaluation
- Profitability analysis for generation and investment options
- Cost–benefit analysis of alternative scenarios and technologies
- Strategic planning
- Support for regulatory and policy decision-making

Future Outlook

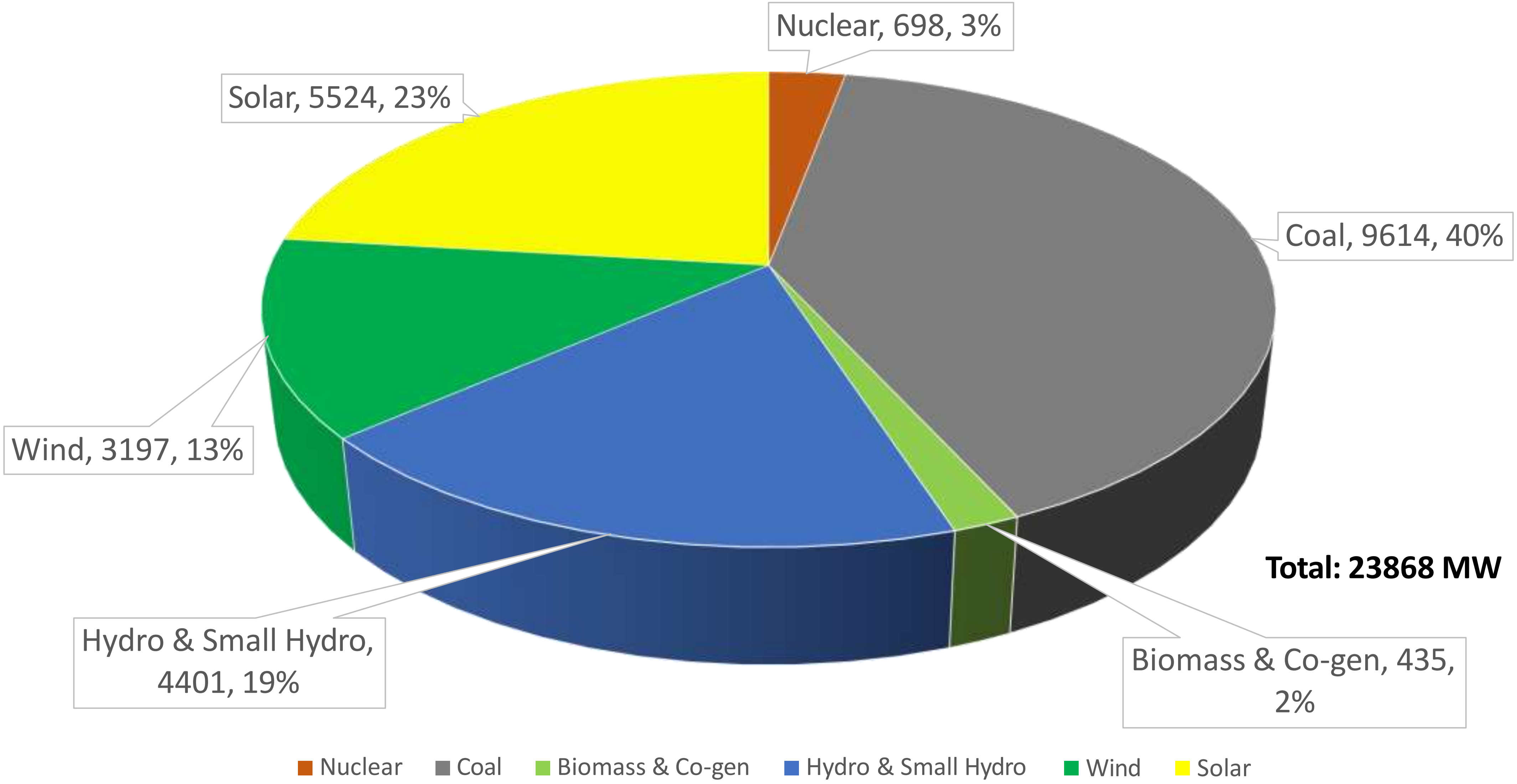
- Resource Adequacy tools to Utilities, SERCs, and SLDCs
- Annual updates to LT-NRAP and LT-DRAP.
- Emergence of new technologies (AI, advanced analytics).
- Improved coordination and system resilience.

Sample LT-DRAP Results

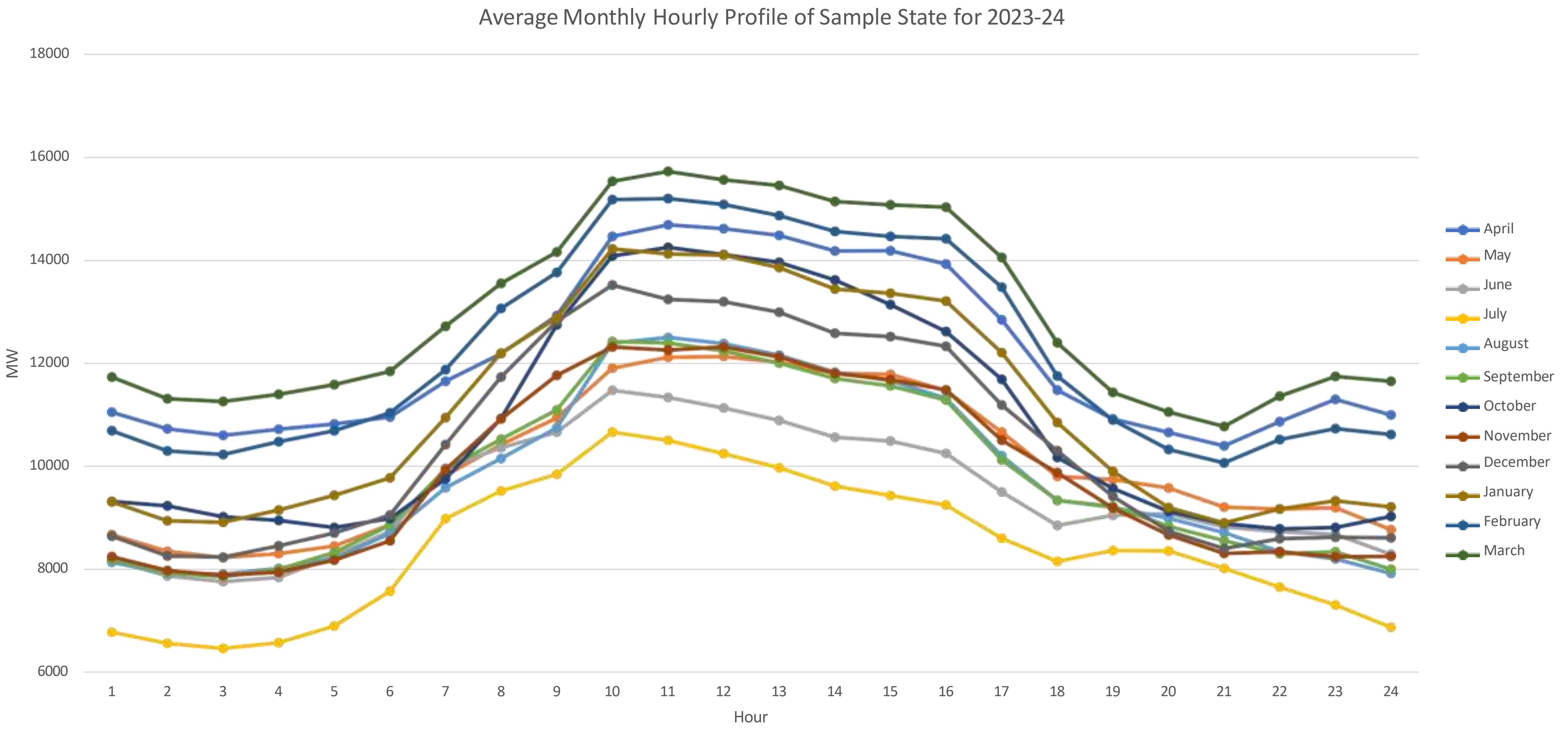
KARNATAKA



Contracted Capacity as on 31.03.2024



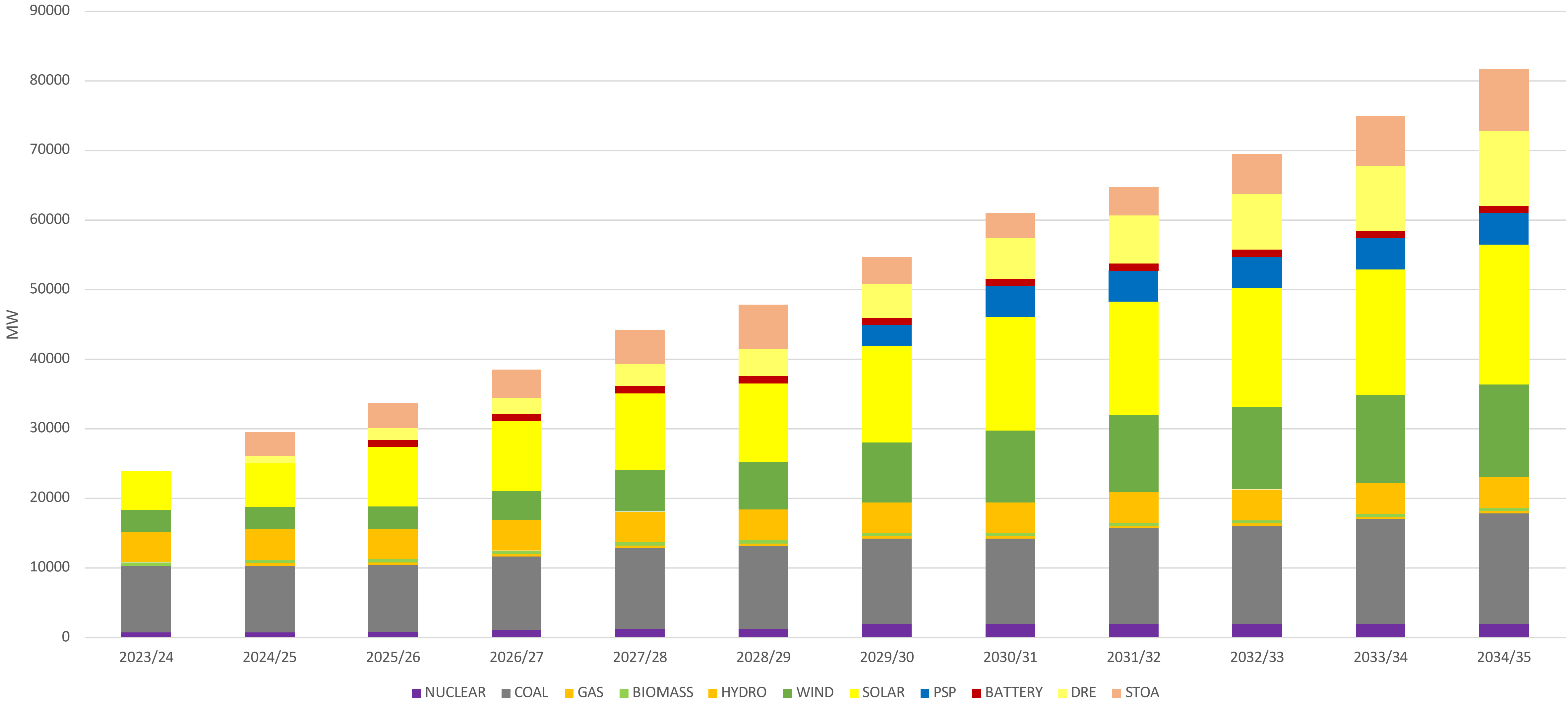
Demand Analysis (FY 2023-24)



Long Term Resource Adequacy Study

- First Un-served Energy is evaluated based on existing and planned capacity.
- Based on the results obtained for unserved energy investment, Options provided to reduce unserved energy-
  - Candidate Coal Capacity
  - RE Capacity
  - Short Term Open Access
  - Energy Storage Systems
- CAPEX, O&M cost, year of availability, maximum capacity, and yearly maximum limit have to be provided for these investment options
- OUTPUT: Annual system capacity requirement fuel-wise.

Projected Contract capacity (Sample State)



Projected Contract capacity of Sample State

	COAL	GAS	NUCLEAR	BIOMASS + CO-GEN	HYDRO + SMALL HYDRO	WIND	SOLAR	Solar DRE	PSP	BATTERY	STOA
2024/25	9614	370	698	435	4401	3197	6277	1133	0	0	3374
2025/26	9614	370	782	435	4401	3197	8587	1713	0	1000	3571
2026/27	10614	370	1003	435	4401	4197	10087	2378	0	1000	4025
2027/28	11614	370	1224	435	4401	5947	11087	3180	0	1000	4943
2028/29	11914	370	1224	435	4401	6897	11287	4003	0	1000	6302
2029/30	12233	370	1924	435	4401	8647	13932	4950	3000	1000	3786
2030/31	12233	370	1924	435	4401	10397	16263	5877	4500	1000	3601
2031/32	13713	370	1924	435	4401	11147	16263	6872	4500	1000	4087
2032/33	14106	370	1924	435	4401	11897	17081	8027	4500	1000	5723
2033/34	15040	370	1924	435	4401	12647	18110	9329	4500	1000	7120
2034/35	15853	370	1924	435	4401	13397	20110	10826	4500	1000	8819

Recommended Year-Wise Capacity Addition

FY	COAL		SOLAR		Wind		Yearly STOA
	Planned	Additional	Planned	Additional	Planned	Additional	Additional
2024/25	0	0	753	0	0	0	3374
2025/26	0	0	2310	0	0	0	3571
2026/27	1000	0	1500	0	1000	0	4025
2027/28	1000	0	1000	0	1000	750	4943
2028/29	300	0	200	0	200	750	6302
2029/30	0	320	1000	1645	1000	750	3786
2030/31	0	0	1000	1331	1000	750	3601
2031-32	1600	0	0	0	0	750	4087
2032/33	0	393	0	818	0	750	5723
2033/34	0	933	0	1028	0	750	7120
2034/35	0	813	0	2000	0	750	8819

FY	Battery	DRE	NUCLEAR	Gas	PSP
	Planned	Additional	Planned	Planned	Planned
2024/25	0	1133	0	370	0
2025/26	1000	580	84.4	0	0
2026/27	0	664	221	0	0
2027/28	0	802	221	0	1000
2028/29	0	823	0	0	0
2029/30	0	948	700	0	2000
2030/31	0	926	0	0	1500
2031-32	0	995	0	0	0
2032/33	0	1155	0	0	0
2033/34	0	1303	0	0	0
2034/35	0	1496	0	0	0

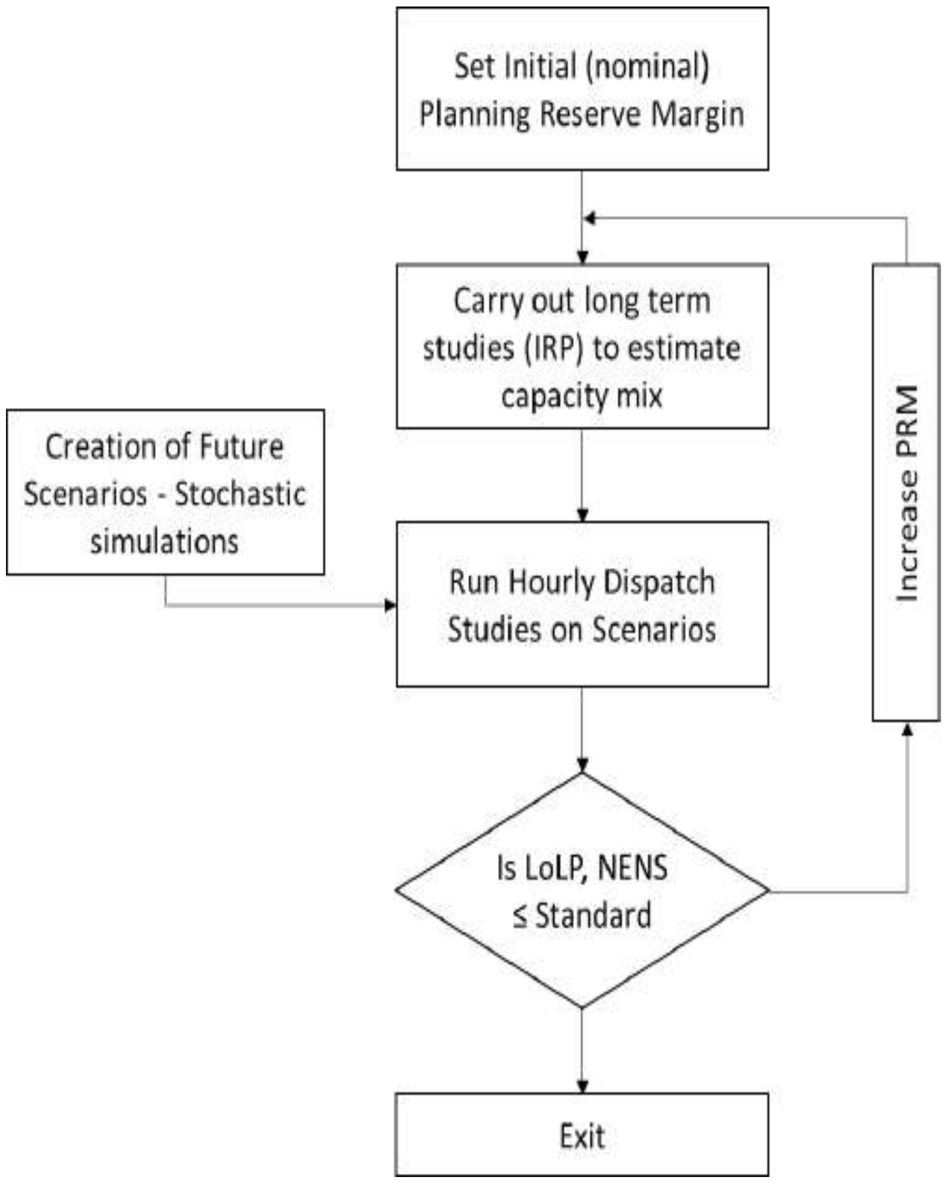
Reliability Study

Reliability is run subject to following conditions to check LOLP and ENS and if required LT is run again to bring the LOLP and ENS within limit.

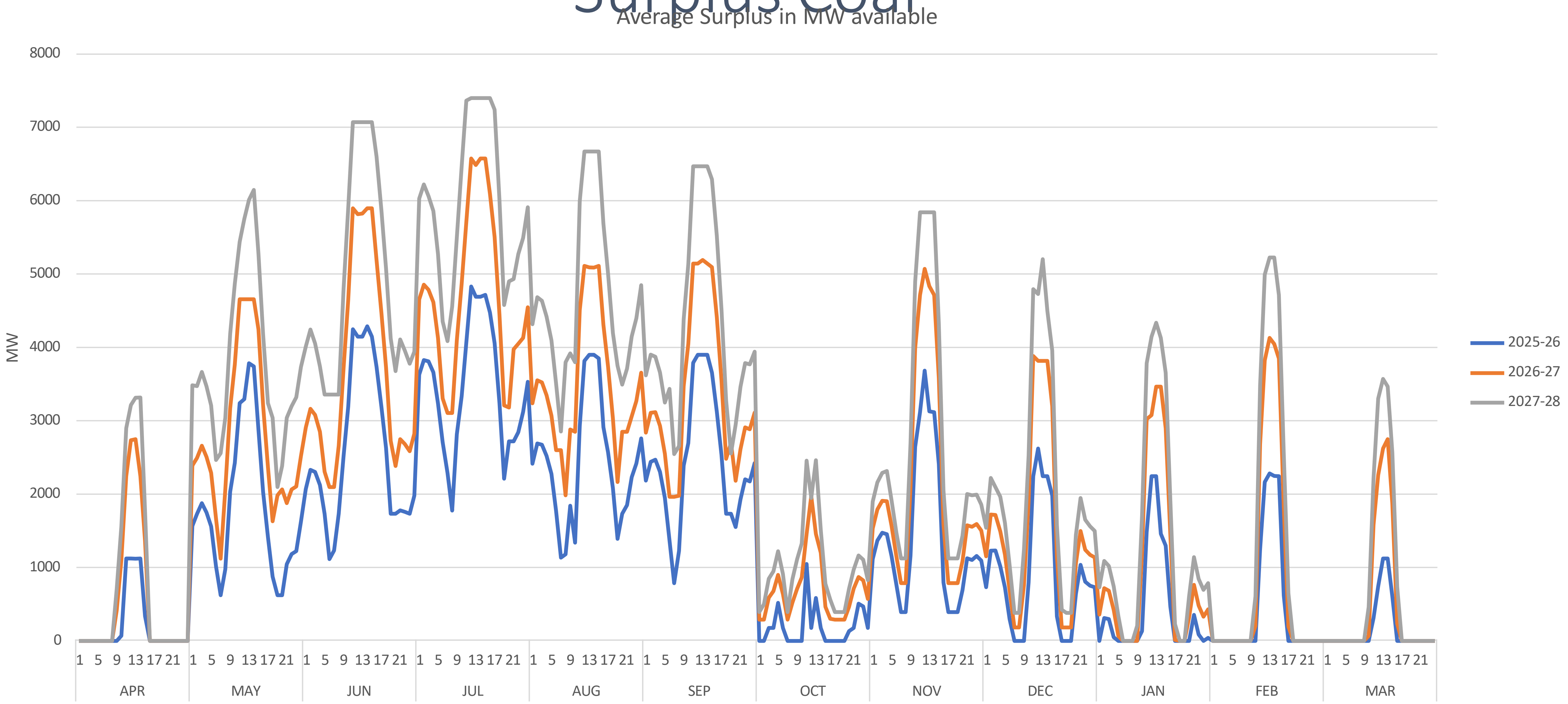
Loss of Load Probability- It is proportion of hours per year when the available generating capacity is insufficient to serve the peak demand. (LoLP of 0.2%)

Energy Not Served(ENS)- it is expected amount of energy which the system will be unable to supply to the consumers as a fraction of total energy requirement. (0.05%)

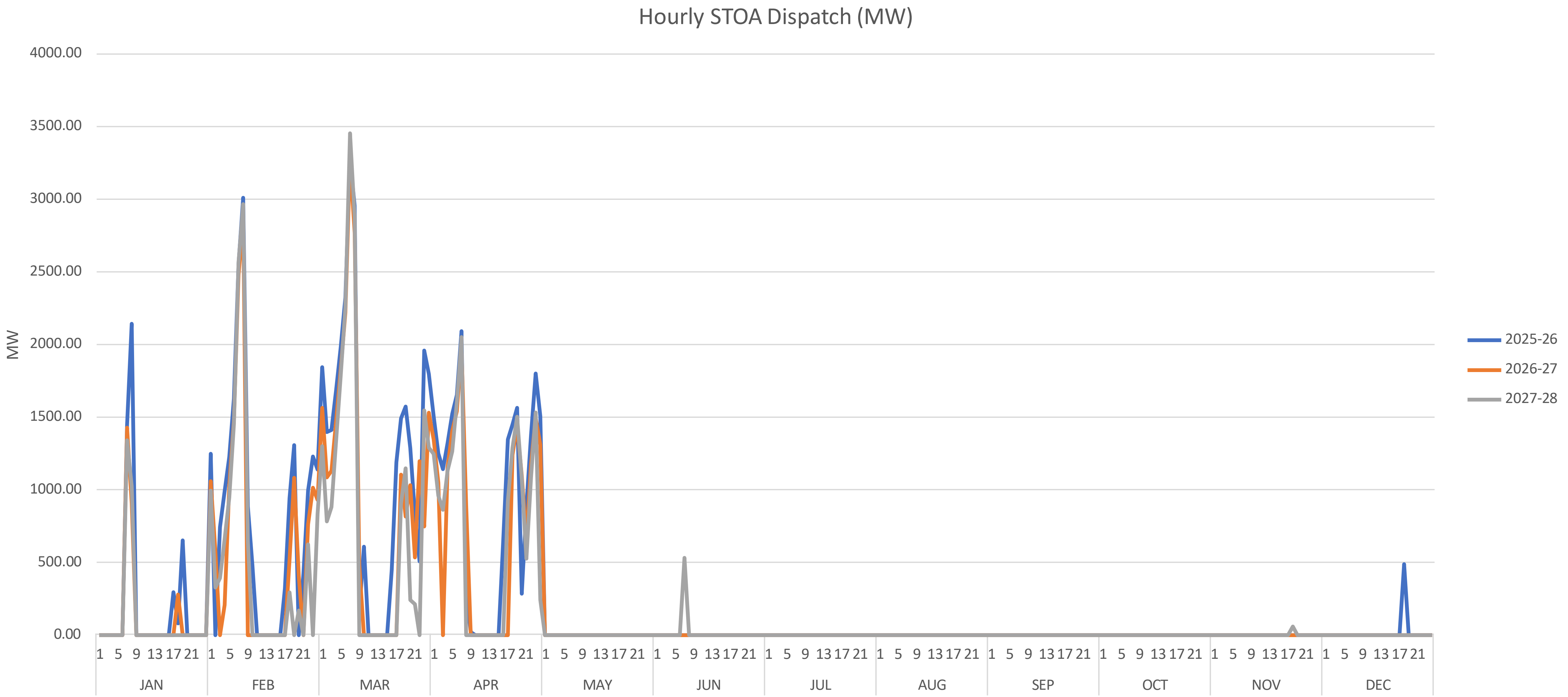
Reliability Study



Surplus Coal



STOA


Hourly STOA Dispatch (MW)
MW
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
1 5 9 13 17 21
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2025-26
2026-27
2027-28

Conclusion

- Annual Peak demand occurs in the month of March.
- Daily peak is mainly observed in the solar hour.
- 2459 MW of additional coal-based capacity required from 2028-29 till 2034-35 onwards (beyond under construction/ planned).
- During the period May to September, surplus coal availability ranges from 2100 MW to 7400 MW in 2027-28.
- Year on year STOA/MTOA/Banking arrangement/Market-based contracts to meet the power deficit in peak hours during March/April is:

Year	2024/25	2025/26	2026/27	2027/28	2028/29	2029/30	2030/31	2031/32	2032/33	2033/34	2034/35
Required Market Contracts	3374	3571	4025	4943	6302	3786	3601	4087	5723	7120	8819

Q&A

- Thank you for your attention!
- Questions and discussions are welcome.

Key Concepts in Resource Adequacy

- Resource Adequacy (RA): Contracting enough capacity to reliably meet peak demand.
- Planning Reserve Margin (PRM): Extra capacity beyond peak load to handle uncertainties.
- LOLP (Loss of Load Probability) and NENS (Normalized Energy Not Served): Metrics for reliability.

Long-Term National Resource Adequacy Plan (LT-NRAP)

- Covers a 10-year planning horizon.
- Determines optimal Planning Reserve Margin (PRM) and generation mix.
- Guides capacity investments and ensures national RA compliance.
- Updated annually by CEA.

Short-Term National RA Plan (ST-NRAP)

- One-year outlook prepared by NLDC.
- Includes demand forecasts, outages, under-construction status.
- Updated annually and aligned with DISCOMs' forecasts.

Distribution Licensee RA Plan (LT-DRAP)

- Each DISCOM prepares a 10-year RA plan.
- Incorporates PRM, forecasted demand, contracted capacity.
- Validated by CEA and submitted to SERC for approval.

RA Planning Process

- Forecast demand over 10 years.
- Assess existing and under-construction resources.
- Identify additional capacity needs.
- Ensure compliance with RAR and PRM.

Procurement Strategy

- Use a mix of Long (75-80%), Medium (10-20%), and Short-term contracts.
- Exclude power exchange procurement from RAR.
- Contract ahead of time to match gestation periods of technologies.

Energy Storage and Flexibility

- Essential for integrating intermittent RE sources.
- Guidelines issued for co-located storage with solar.
- Storage can enhance reliability and reduce system costs.

Capacity Credit Methodologies

- Top Demand Hours: Used for existing resources.
- Top Net Load Hours: Accounts for system stress.
- ELCC (Expected Load Carrying Capability): Advanced, stochastic modeling approach.

Scenario Modelling

- Incorporates uncertainty: demand, RE generation, outages.
- Uses Monte Carlo simulations.
- Tests system response under multiple future scenarios.

Optimal PRM & System Cost

- Balance reliability and cost efficiency.
- Use Marginal Cost of Reducing Load Shed (MCRLS) to find economic PRM.
- Target: PRM where MCRLS equals Value of Lost Load (VoLL).

Methodology Summary

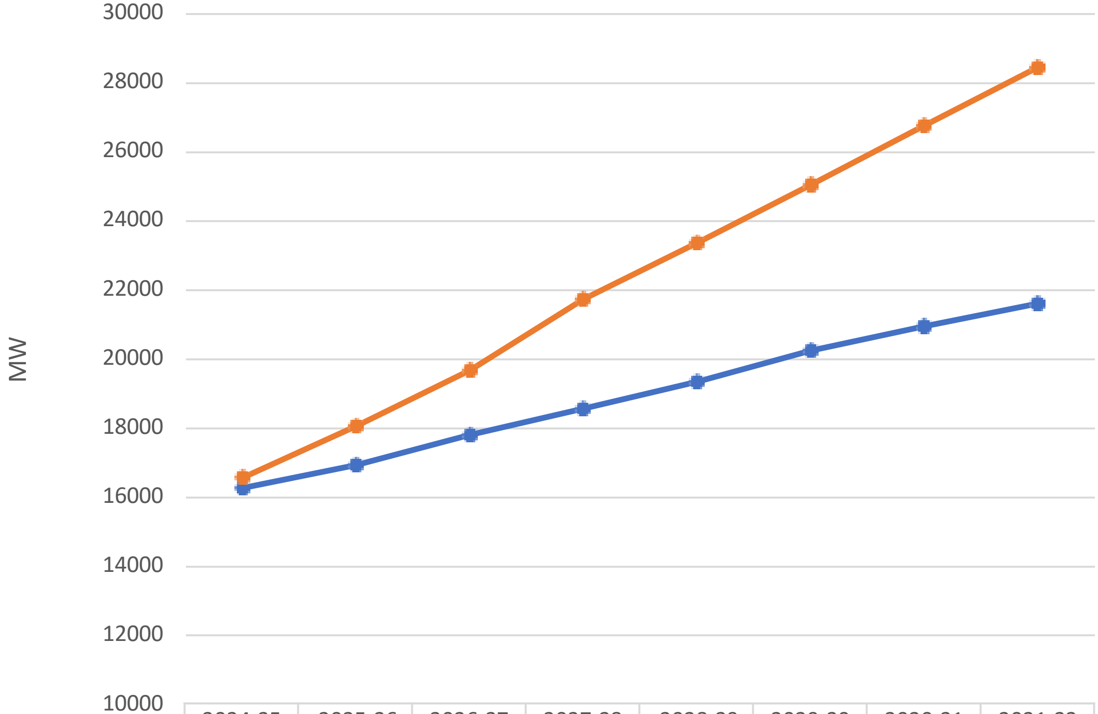
- Demand forecast (hourly resolution).
- Optimization with technical and policy constraints.
- Model includes RE profiles, storage, ramping limits, reserve needs.
- Outputs: generation mix, investment needs, RA compliance.

Compliance Monitoring

- Timeline-driven approach from May to March each year.
- CEA, SLDC, RLDC, and NLDC roles defined.
- Shortfalls addressed via national auction or regulatory action.

Demand Projections

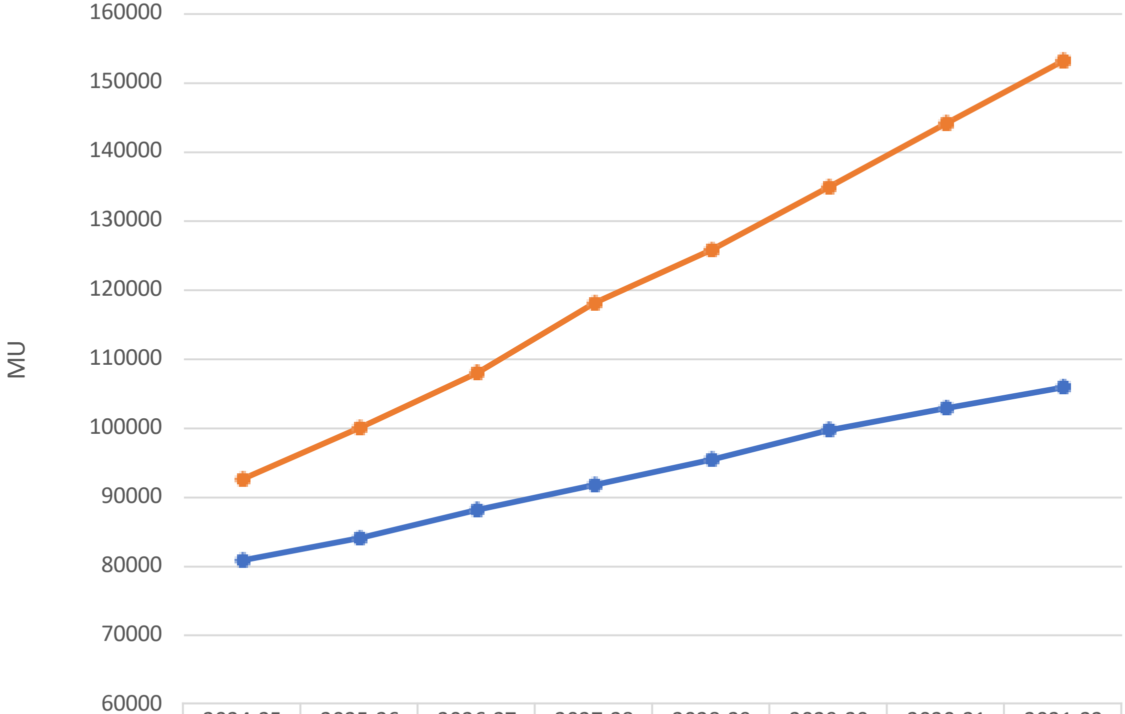
Peak Demand Projections



	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32
20th EPS	16277	16947	17810	18578	19352	20254	20954	21613
Karnataka	16579	18075	19690	21745	23372	25051	26765	28453

20th EPS   Karnataka

Energy Requirement Projections



	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32
20th EPS	80922	84132	88232	91852	95486	99758	102973	105970
Karnataka	92648	100066	107998	118181	125868	134910	144142	153230

20th EPS   Karnataka

Defining Features of STELLAR

- Chronological modelling
- Co-optimization of energy and ancillary services
- Unit commitment constraints
- Integrated Demand Response
- Transmission modelling