सत्यमेव जयते

Report on
Resource Adequacy Plan for Rajasthan
(2025-26 to 2035-36)

Government of India
Ministry of Power
Central Electricity Authority

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Disclaimer

This Resource Adequacy study conducted for the state of Rajasthan, is based on the data and inputs provided by Rajasthan Urja Vikas Nigam Limited (RUVNL) and the results of the study are dependent on the inputs provided by the state.

Further, as per the Resource Adequacy Guidelines dated 28th June 2023, each Distribution Licensee is required to prepare a Resource Adequacy Plan (RAP) for a 10-year horizon, known as the Long-Term Distribution Licensee Resource Adequacy Plan (LT-DRAP), which shall be vetted/validated by the Central Electricity Authority (CEA). To support the utility in this process, CEA has facilitated the study and prepared this report. The responsibility for implementing the recommendations, ensuring adequacy of resources, and taking further actions rests entirely with the utility.

Executive Summary

Ministry of Power had notified the Electricity (Amendment) Rules in December 2022. As per Rule 16 of the Electricity (Amendment) Rules, the Ministry of Power has notified Resource Adequacy (RA) Guidelines. According to these Guidelines, the Central Electricity Authority (CEA) is entrusted with the responsibility of preparing the Long-Term National Resource Adequacy Plan (LT-NRAP). Further, each Distribution Utility is required to carry out a Long-Term Distribution Licensee Resource Adequacy Plan (LT-DRAP) to reliably meet its peak and energy requirements.

As per the Resource Adequacy Guidelines dated 28th June 2023, each Distribution Licensee shall undertake a Resource Adequacy Plan (RAP) with a 10-year planning horizon LT-DRAP to meet its own peak and electrical energy requirements. This plan shall be vetted/validated by the CEA to leverage the benefits of national-level optimization for the Distribution Licensees. The LT-DRAP shall be prepared by the Distribution Licensees on an annual rolling basis, factoring in the already contracted capacity and optimizing the requirement for additional capacity.

The Government of India has also recently gazette notified the Renewable Purchase Obligation (RPO) trajectory up to 2029-30 vide gazette notification dated 20th October 2023, which mandates that a specified portion of energy consumption must be met from renewable energy sources.

To support the utility in fulfilling this requirement, CEA, in collaboration with the State, initially conducted a Resource Adequacy (RA) study with a planning horizon up to FY 2031-32, based on the data received from the State and in compliance with the then prevailing RPO trajectory specified in the Ministry of Power's Office Memorandum dated 22nd July 2022 and its subsequent corrigendum dated 19th September 2022. This study has now been updated and extended to cover the period up to FY 2035-36, incorporating the latest data furnished by the State and planning assumptions. The RPO requirement for the utility has also been assessed in accordance with the recent gazette notified trajectory.

The electricity energy requirement and peak demand for Rajasthan is increasing with a CAGR of 5.3% and 4.5% respectively from 2025-26 to 2035-36 as forecasted in the 20th EPS Mid-term review. For satisfying resource adequacy i.e., meeting the electricity demand reliably and at affordable cost, the state needs to methodically plan its capacity expansion either by investing or by procuring power. In view of the reduction in cost of solar panels and newer technology options like battery energy storage systems, planning for long term optimal generation capacity mix gains tremendous importance so as the future generation capacity mix is cost effective as well as environment friendly.

A study is carried out for Rajasthan considering the existing contract capacity and planned capacity addition. It was found that the state likely contracted capacity may not be sufficient to

meet the projected demand. Further, the total unserved energy in the year 2035-36 is expected to be about 35.8 BU which is about 17% of the annual projected energy demand during the year 2035-36.

To find out the least cost option for generation capacity expansion for the period 2025-26 to 2035-36, long-term study is carried with an objective to minimize the total system cost of generation including the cost of anticipated future investments while fulfilling all the technical/financial constraints associated with various power generation technologies. Additionally, reliability study has been carried out to determine the probability of unmet demand and hours by implementing the variation in demand, RE and forced outage of thermal generators (Coal/ Lignite) etc.

Generation capacity expansion pathways have been considered for the long-term study based on the yearly capacity addition plans of the Rajasthan along with RPO constraints for solar and wind technologies. The Renewable capacities have been assessed in view of adherence to RPO notified by Ministry of power considering the fungibility among different sources.

The Resource adequacy studies have projected likely optimal capacity mix for future years till 2035-36 which is able to meet anticipated demand reliably at every instance. Based on the study, the likely total projected contracted capacity for the year 2035-36 is around 86,933 MW which consists of 7864 MW from coal, 601 MW from gas, 1157 MW from nuclear, 212 MW from biomass, 2234 MW from hydro, 10266 MW from wind, 25513 MW from solar, 15002 MW from Distributed Renewable Energy (DRE) sources, 100 MW of PSP, 13984 MW/63851 MWh from Battery Energy Storage System (BESS). Further, in addition to this, 1687 MW of MTOA/STOA arrangement will be required. This capacity shall be able to meet the projected demand with prescribed reliability criteria.

1.0 Introduction

Ministry of Power has notified Electricity (Amendment) Rules, 2022 in December 2022. Rule 16 (I) of the said rules stipulates that "A guideline for assessment of resource adequacy during the generation planning stage (one year or beyond) as well as during the operational planning stage (up to one year) shall be issued by the Central Government in consultation with the Authority". Accordingly, the Resource Adequacy Guidelines have been notified in June, 2023 by Ministry of Power in consultation with Central Electricity Authority.

Resource Adequacy is generally defined as a mechanism to ensure that there is an adequate supply of generation resources to serve expected demand reliably at least cost. A key aspect of resource adequacy planning is to ensure that adequate generation capacities are available, round-the-clock, to reliably serve demand, under various scenarios. This naturally translates into the need for ensuring adequate reserve margin, which could cater to varying levels of demand and supply conditions in the grid. In the wake of high RE generation, it is important to understand demand-supply situation in the grid precisely due to high seasonality and intermittency in RE generation. Resource Adequacy exercise may also help in assessment of capacity requirement to be tied up or contracted on long term, medium term, and short-term basis.

Further, Ministry of Power vide notification dated 20th October, 2023 had notified the RPO trajectory for the states/Discoms. Based on the trajectory specified the hydro, wind and other (solar, biomass etc.) RPO quantum in million units (MUs) has been calculated to find additional quantum of renewable capacity that the states/Discoms have to contract in addition to its existing/planned capacity to meet their RPO targets.

To support the utility in fulfilling the Resource Adequacy Guidelines and complying with the Renewable Purchase Obligation (RPO) notification, CEA has carried out the RA study for the state of Rajasthan based on inputs furnished by RUVNL. The study recommends an optimal resource mix up to FY 2035-36, taking into account technical and financial parameters associated with various capacities. It aims to optimize long-term power procurement while ensuring resource adequacy to meet demand on a 24×7 basis, considering variations in demand, RE generation, and forced outages of thermal capacities. The study assesses the Planning Reserve Margin (PRM) required by the state to account for the aforementioned uncertainties, ensuring that demand can be reliably met throughout the year.

Prior to this, CEA had conducted the RA study for the state up to FY 2031-32, based on inputs from RUVNL and in accordance with the then prevailing RPO trajectory specified in the Ministry of Power's Office Memorandum dated 22nd July 2022 and its subsequent corrigendum dated 19th September 2022.

2.0 Highlights of the Previous RA Study (Up to FY 2031–32)

1. In the earlier Resource Adequacy (RA) study, the financial year 2022-23 was considered as the base year, and the study covered the period from 2023-24 to 2031-32. The fuel-wise contracted capacity as on 31st March, 2023:

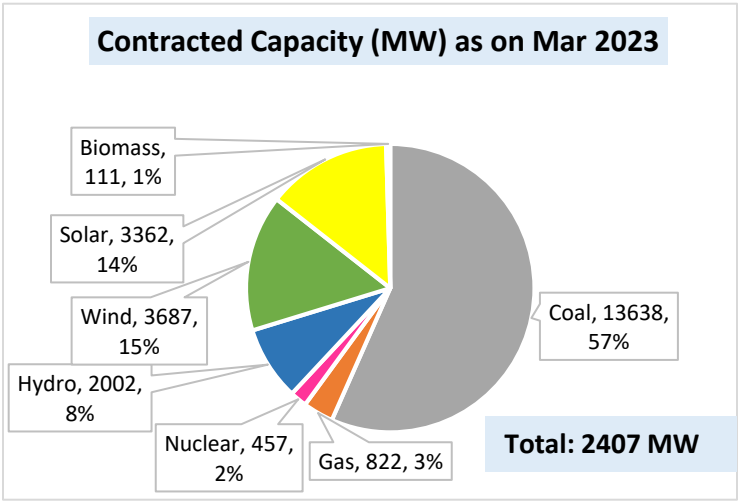


Figure 2.1.1 Contract Capacity 2022-23

2. The hourly demand pattern for 2022-23 was analysed.

3. The peak demand and electrical energy projections that was considered in the study:

	2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32
Energy Projections (MU)	112368	119167	126118	133550	141260	149303	158836	165398	171883
Year on Year Growth (%)		6.05%	5.83%	5.89%	5.77%	5.69%	6.39%	4.13%	3.92%
Peak Demand Projections (MW)	18979	20284	21680	23172	24766	26470	28291	30237	32317
Year on Year Growth (%)		6.88%	6.88%	6.88%	6.88%	6.88%	6.88%	6.88%	6.88%

4. The actual peak demand and energy requirement of the state observed during the 2023-24 and 2024-25 is tabulated below based on the Power Supply Position (PSP) report of CEA:

Year	Actual Energy Requirement (in MU)	Actual Peak Demand (in MW)
2023-24	1,07,422	18,128
2024-25	1,13,833	19,165

5. To meet the above projected peak demand and energy requirement reliably, the source-wise projected capacity (in MW) as outlined in the previous report is tabulated below:

	Coal	Gas	Nuclear	Biomass	Hydro	Wind	Solar	PSP	Battery	STOA*
2023/24	13919	822	457	111	2181	4888	6721	0	0	1369
2024/25	13919	822	807	234	2328	5082	8399	100	0	2718
2025/26	14219	822	1157	234	2493	5704	10518	100	0	3390
2026/27	14219	822	1157	234	2646	6413	12685	100	0	4480
2027/28	15539	822	1157	234	2827	7202	14888	100	0	4600
2028/29	16911	822	1157	234	3030	8063	17043	100	439	4347
2029/30	17699	822	1157	234	3239	8931	19324	100	1135	4409
2030/31	18382	822	1157	234	3292	9148	20585	100	1287	5490
2031/32	19710	822	1157	234	3344	9362	22133	100	1642	6000

*****The STOA/MTOA value represents the peak power requirement in MW and it was recommended that this requirement may be met through power procurement from the market or through bilateral agreements.

6. The year-wise planned and additional capacity contract addition (in MW) for the above tabulated cumulative capacity is detailed below:

	COAL		**NUCLEAR**	**BIOMASS**	**HYDRO**	
Year	**Planned**	**Additional**	**Planned**	**Planned**	**Planned**	**Additional**
2023/24	281	0	0	0	179	0
2024/25	0	0	350	123	56	91
2025/26	300	0	350	0	0	165
2026/27	0	0	0	0	0	153
2027/28	1320	0	0	0	0	181
2028/29	925	447	0	0	0	203
2029/30	0	788	0	0	0	209
2030/31	0	683	0	0	0	53
2031/32	0	1328	0	0	0	52
TOTAL	**2826**	**3246**	**700**	**123**	**235**	**1107**
	WIND		**SOLAR**		**PSP**	**Battery (4 hours)**
Year	**Planned**	**Additional**	**Planned**	**Additional**	**Planned**	**Additional**
2023/24	1201	0	3359	0	0	0
2024/25	0	194	300	1378	100	0
2025/26	0	622	1000	1119	0	0
2026/27	0	709	0	2167	0	0
2027/28	0	789	0	2203	0	0
2028/29	0	861	0	2155	0	439
2029/30	0	868	0	2281	0	696
2030/31	0	217	0	1261	0	152
2031/32	0	214	0	1548	0	355
TOTAL	**1201**	**4474**	**4659**	**14112**	**100**	**1642**

3.0 Rajasthan RA Study (from 2025-26 to 2035-36)

3.1 Present Power Scenario in Rajasthan

The current power supply position for Rajasthan is shown in the Table 1 below:

Table 1 Power Supply Position of Rajasthan

Power Supply Position						
Year	**Energy required (MU)**	**Energy supplied (MU)**	**Gap (MU)**	**Peak Demand (MW)**	**Peak Met (MW)**	**Demand not met (MW)**
2021-22	89,814	89,310	504	15,784	15,784	0
2022-23	101,801	100,057	1,745	17,399	17,206	193
2023-24	107,422	106,806	616	18,128	18,128	0
2024-25	113,840	113,537	304	19,165	19,165	0

As of March 2025, the total contracted capacity for Rajasthan is 27,494 MW. Out of the total contracted capacity (CC), the share of non-fossil fuel-based CC is 49 %.

The fuel-wise contracted capacity as on 31st March, 2025 is given in Table and Figure below:

Table 2 Fuel-wise Contracted Capacity as on March 2025

Source	Contracted Capacity (MW)	Percentage (%)
Coal	13425	48.83%
Gas	601	2.19%
Nuclear	457	1.66%
Hydro	1962	7.14%
Wind	4566	16.61%
Solar	5623	20.45%
Biomass	182	0.66%
Distributed RE (DRE)	678	2.47%
Total	**27494**	**100%**

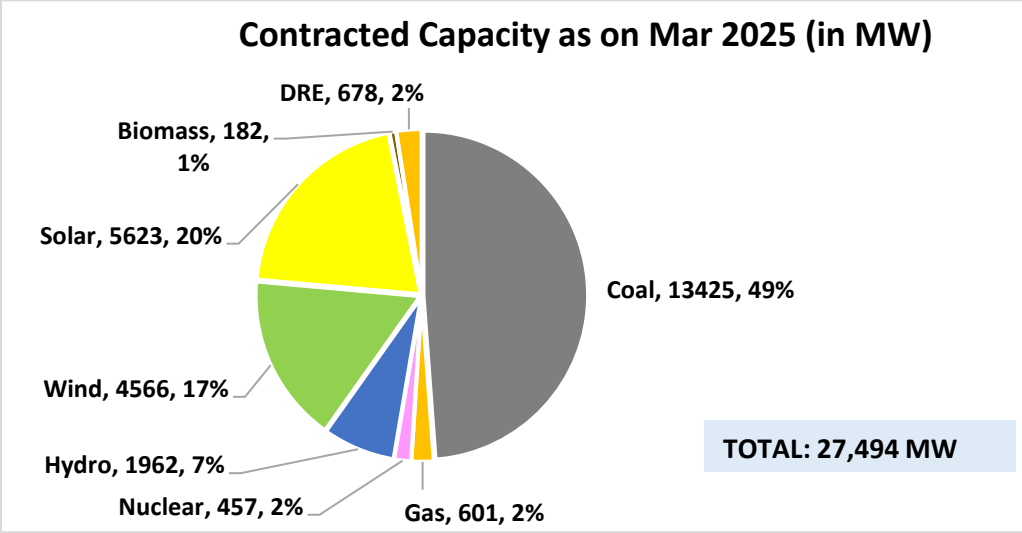


Figure 1 Fuel-wise Contracted Capacity (in MW) as on 31st March, 2025

3.2 Demand Analysis of the FY 2023-24

Hourly demand pattern of 2023-24 was analyzed and it was observed that peak electricity demand in Rajasthan occurs during the winter months, specifically in January and February. Notably, the state experiences peak demand during the solar hours in January. Overall, the demand during the solar hours in these two months is significantly higher than in the rest of the year. Furthermore, the diurnal variation (i.e., the difference in demand between solar and non-solar hours) is comparatively lower during the months of May to September, as opposed to the more pronounced variations seen in the other months.

The month wise variation in average hourly demand observed for the year 2023-24 is shown in Figure 2 given below:

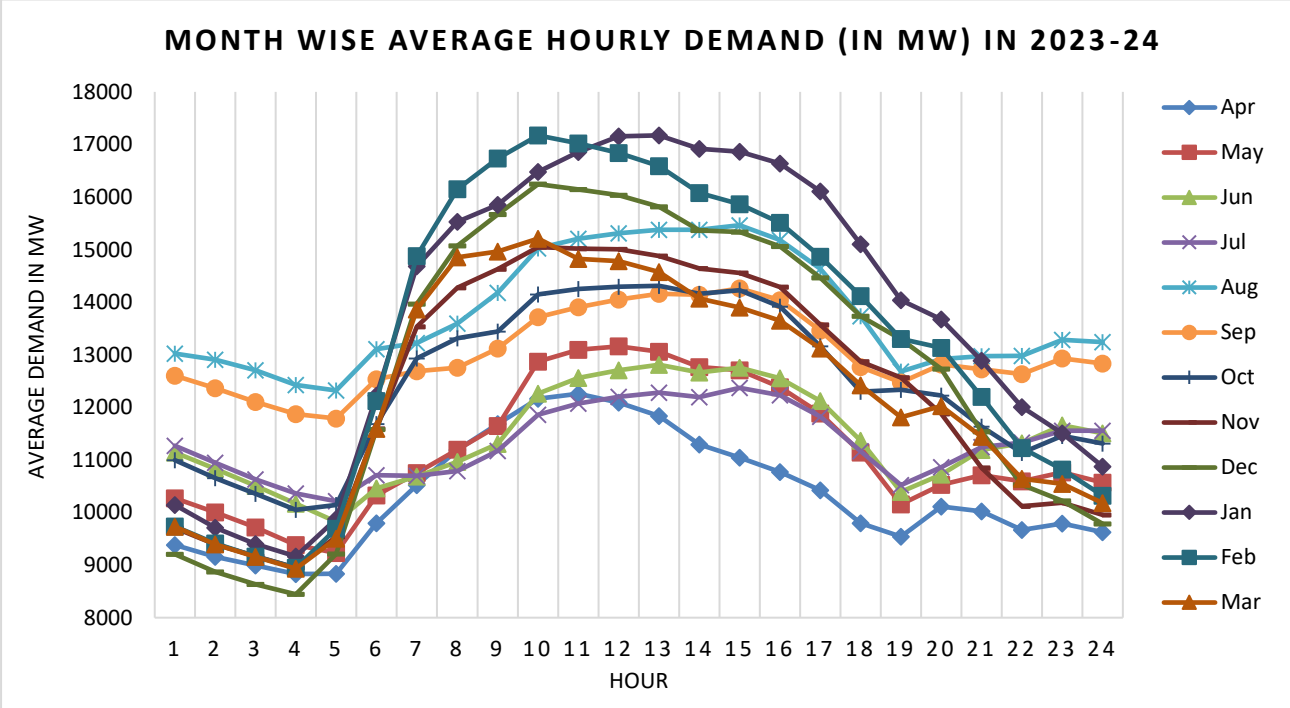


Figure 2 Average Hourly Demand Variation (Month-wise) for 2023-24

From the hourly demand data of 2023-24 the daily peak during solar hours (06:00 to 18:00 hrs) and non-solar hours are plotted in the below figure.

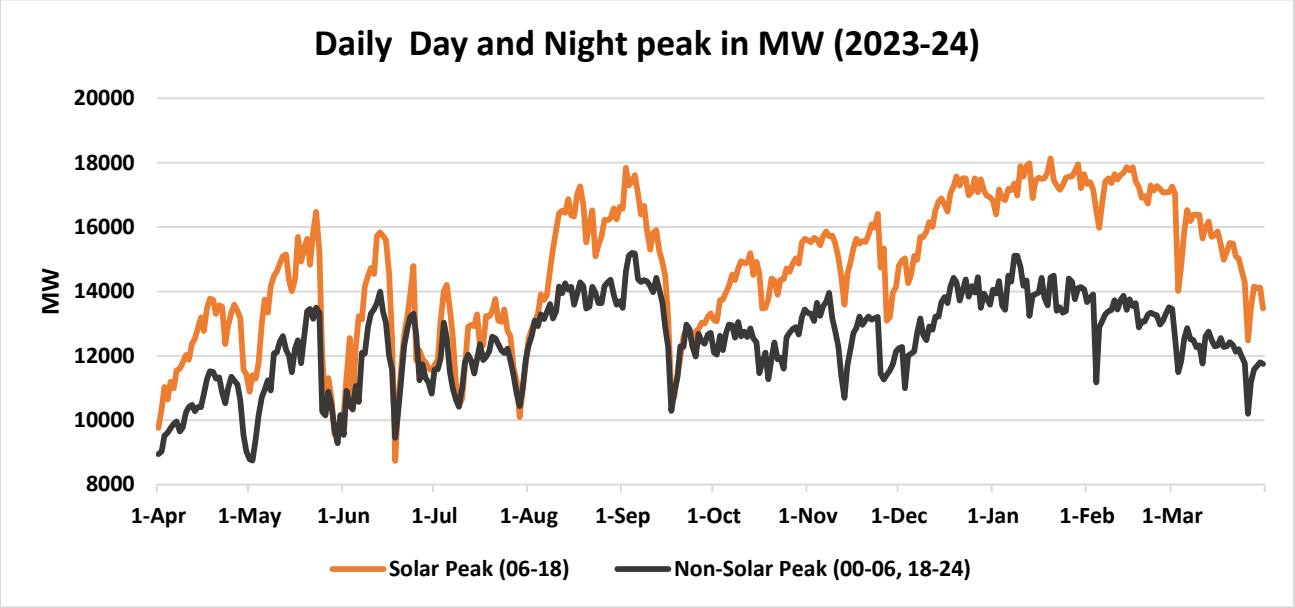


Figure 3 Day and Night Peak in MW for the year 2023-24

As seen in figure 3, the daily peak demand occurs during solar hours and the difference in the peak observed in solar and non-solar hours is significant in the months of October to March.

The hourly demand pattern of 2023-24 was analysed for finding out the number of occurrences of the peak and near peak demand. Such instances are critical for study purpose as it is necessary to ensure resource adequacy during such instances with an optimal mix of long-term, medium-term and short-term contracts.

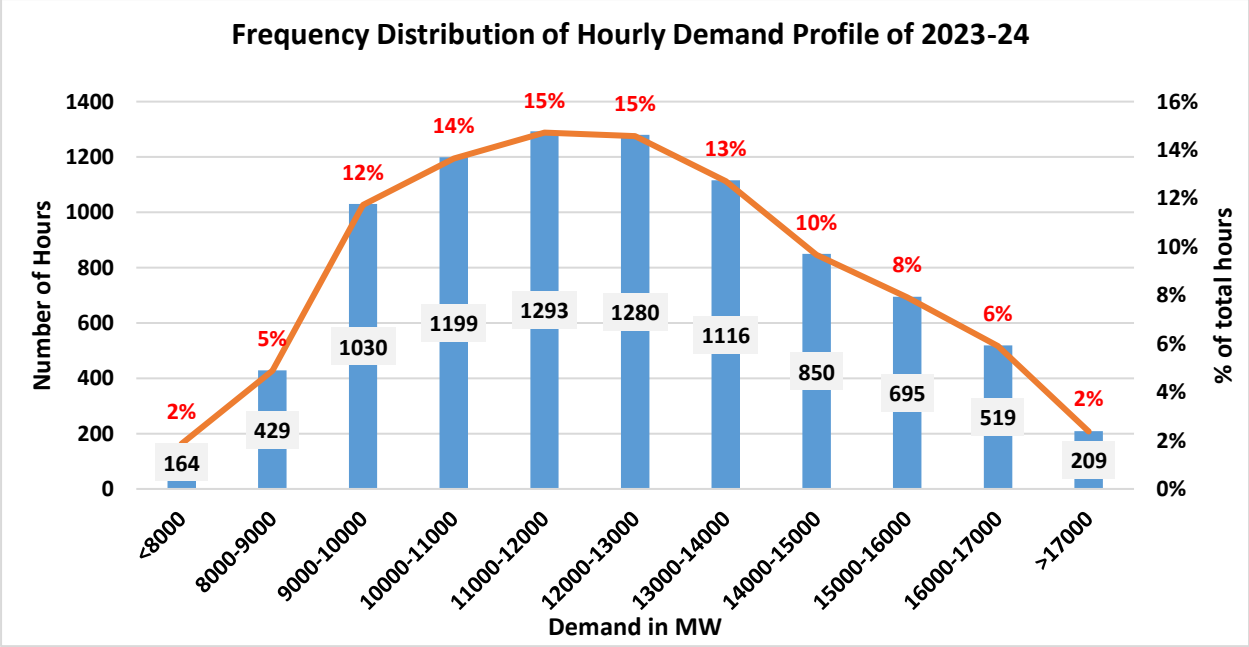


Figure 4 Frequency Distribution of Hourly Demand Profile of 2023-24

4.0 Principles of Generation Planning

The objective of the Generation Planning process is to obtain an optimal generation capacity mix in the least cost manner to meet the demand at every instance of time while ensuring the most efficient use of resources. The purpose of generation planning studies is not to predict or forecast the future, but a collaborative effort to understand and explore the key factors and relationships shaping the future of the power sector. Planning is therefore an activity encompassing balancing demand and supply at all instances of time and at all locations, which makes it a regular ongoing process.

The major aspects considered in the planning process are:

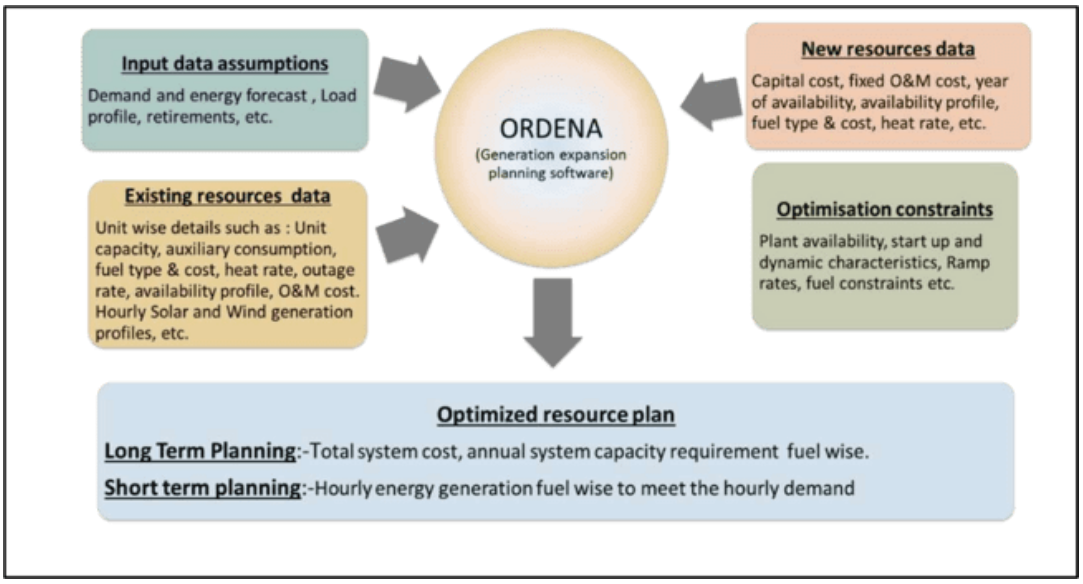
i) To Supply 24*7 reliable power to consumers
ii) To achieve objectives of all policies of the Government of India such as RPO trajectory, RE capacity addition
iii) To achieve sustainable development.
iv) To fulfill desired operational characteristics of the system such as reliability and flexibility.
v) Most efficient use of resources.
vi) Fuel availability

4.1 Generation Expansion Planning Tool -ORDENA

The studies were carried out using a generation expansion planning model namely ORDENA. ORDENA is a mixed integer linear optimization program that minimizes the Net Present Value (NPV) of investment and operating costs subject to several constraints. The major constraints include balancing electricity supply and demand, resource supply limits, planning and operating reserve limits, and policy targets. These constraints are met considering a broad portfolio of conventional generation, renewable generation, and storage.

ORDENA has a reliability module to determine the trustworthiness of the system using Monte Carlo simulations. The software is also capable of carrying out hourly/sub-hourly economic generation dispatch, considering all the technical constraints associated with various generation technologies.

The schematic diagram of the software is given in Exhibit.



5.0 Reliability Analysis

One of the main criteria of resource adequacy studies is to determine the reliability of the system to meet the demand adequately at very instance of time. This reliability is measured via two indices (i.e.) LOLP (Loss of Load Probability) and EENS (Expected Energy Not Served). These indices have been defined in resource adequacy guidelines as below:

- **Loss of Load Probability (LOLP)**: Measure of the probability that a system's load may exceed the generation and firm power contracts available to meet that load in a year. E.g., 0.0274 % probability of load being lost.
- **Expected Energy Not Served (EENS):** Expected amount of energy (MWh) that may not be served for each year within the planning period under study. It is a summation of the expected number of megawatt hours of demand that may not be served for the year. This is an energy-centric metric that considers the magnitude and duration of energy being not served, calculated in Mega Watt hours (MWh). The metric can be normalized (i.e., divided by total system load) to create a Normalized Energy Not Served (NENS) metric.

Monte Carlo /Stochastic simulation has been used to factor-in the uncertainty associated with various generation resources and demand. It is an approach which is used to predict the probability of a variety of outcomes when the potential for random variables is present as compared to deterministic modelling of economic dispatch model. Monte Carlo simulation helps in analysing the randomness associated with RE energy resource, demand pattern changes and forced outages of plant. A large no of random samples of these variables are simultaneously simulated to ascertain system reliability indices (i.e. Loss of load probability LOLP & Energy Not

Served (ENS)) & the system robustness in case of above variation of system parameters.

Planning Reserve Margin (PRM): To meet the prescribed standard of LOLP / NENS conditions, sufficient reserve margins need to be maintained in the system for adequately addressing the demand and supply variations. Planning Reserve Margin (PRM) is the predominant metric used to ensure adequacy of generation resources in the system. PRM in a power system is expressed as a certain percent of peak load forecast of the system.

5.1 Demand variation

The variation in demand pattern for last 2 years has been analyzed. The hourly demand variation for consecutive years (i.e., 2022-23 and 2023-24) has been analyzed. The Demand pattern variation of 2022-23 and 2023-24 is shown below.

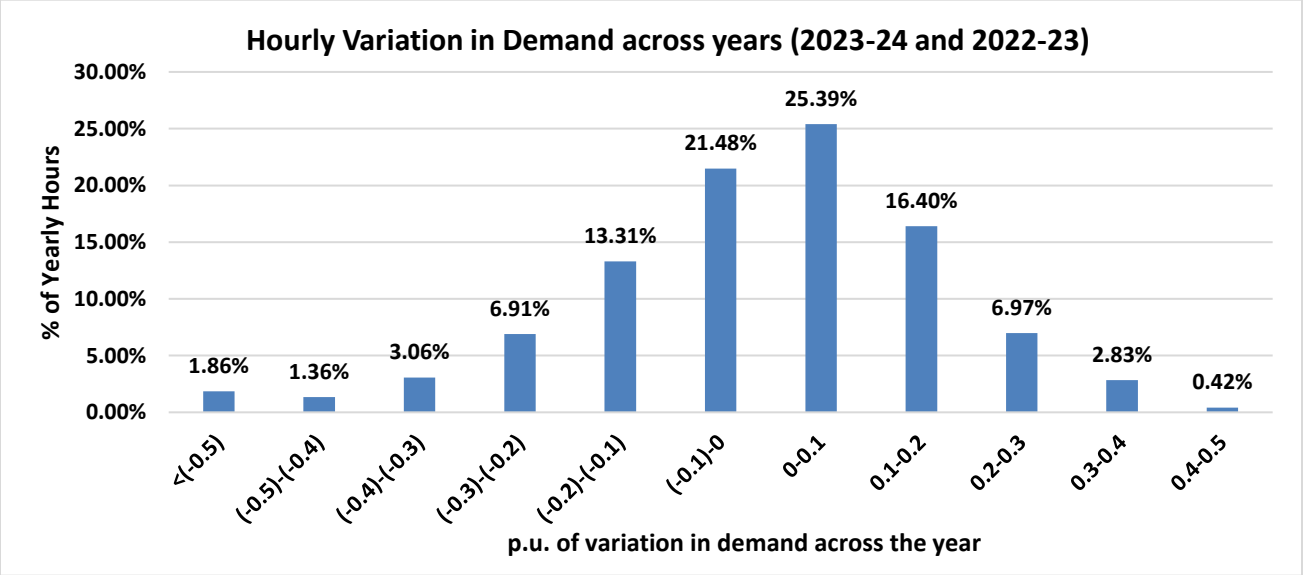


Figure 5 Hourly Variation in Demand across years

It can be observed that the hourly demand typically varies ±20% for 76.59% of instances. This variation is primarily due to temperature, weather parameter or any random outages of transmission line and generation units etc. This variation has been captured in the reliability study by varying the projected hourly demand for the future years by varying ±20% by introducing a random variable (with normal distribution) for demand as per observed behavior over the years.

5.2 RE variation

In the Long-term capacity expansion planning studies, a particular profile for Solar is considered based on the observed solar generation data to determine the optimal capacity mix. However, due to intermittent nature of these sources the generation from these non-dispatchable sources may vary across years. As per the analyses carried out based on historical generation data, solar and hydro based generation has been varied by ± 10 % and wind generation has been varied by

± 50% to incorporate the variation in these generation sources and plan for requisite measures to mitigate such behavior.

5.3 Forced Outage of Thermal Generators

The average forced outage rate of thermal generators is typically at 10% with ±5% variation. The same has been incorporated in the model.

Based on these variations reliability studies are carried out to ascertain robustness of the system.

6.0 Inputs/Assumptions for the Study

i) The electrical energy requirement of Rajasthan, furnished by RUVNL and projections available in the 20th EPS (Electric Power Survey) Mid-term review is tabulated below. The utility's peak demand projections is found to be on the higher side however the electrical energy requirement projections is close to the 20th EPS mid-term review projections.

Table 3 Future Demand Projection as provided by utility and as per mid –term review of 20th EPS

	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32	2032-33	2033-34	2034-35	2035-36
Peak Demand (in MW)												
RUVNL Peak Demand Projections (in MW)	20284	21680	23172	24766	26470	28291	30237	32317	34540	36916	39456	
Year on Year Growth		6.9%	6.9%	6.9%	6.9%	6.9%	6.9%	6.9%	6.9%	6.9%	6.9%	
20th EPS Mid-term review Peak Demand Projections (MW)	19344	20796	22256	23494	24762	25971	27078	28110	29171	30154	31068	32168
Year on Year Growth		7.5%	7.0%	5.6%	5.4%	4.9%	4.3%	3.8%	3.8%	3.4%	3.0%	3.5%
Energy Requirement (in MU)												
RUVNL Energy Projections (in MU)	119167	126118	133550	141260	149303	158836	165398	171883	178622	185626	192904	
Year on Year Growth		5.8%	5.9%	5.8%	5.7%	6.4%	4.1%	3.9%	3.9%	3.9%	3.9%	
20th EPS Mid-term review Energy Projections (in MU)	114306	122868	131476	140331	149533	158537	167073	175289	183819	191995	199857	206934
Year on Year Growth		7.5%	7.0%	6.7%	6.6%	6.0%	5.4%	4.9%	4.9%	4.4%	4.1%	3.5%

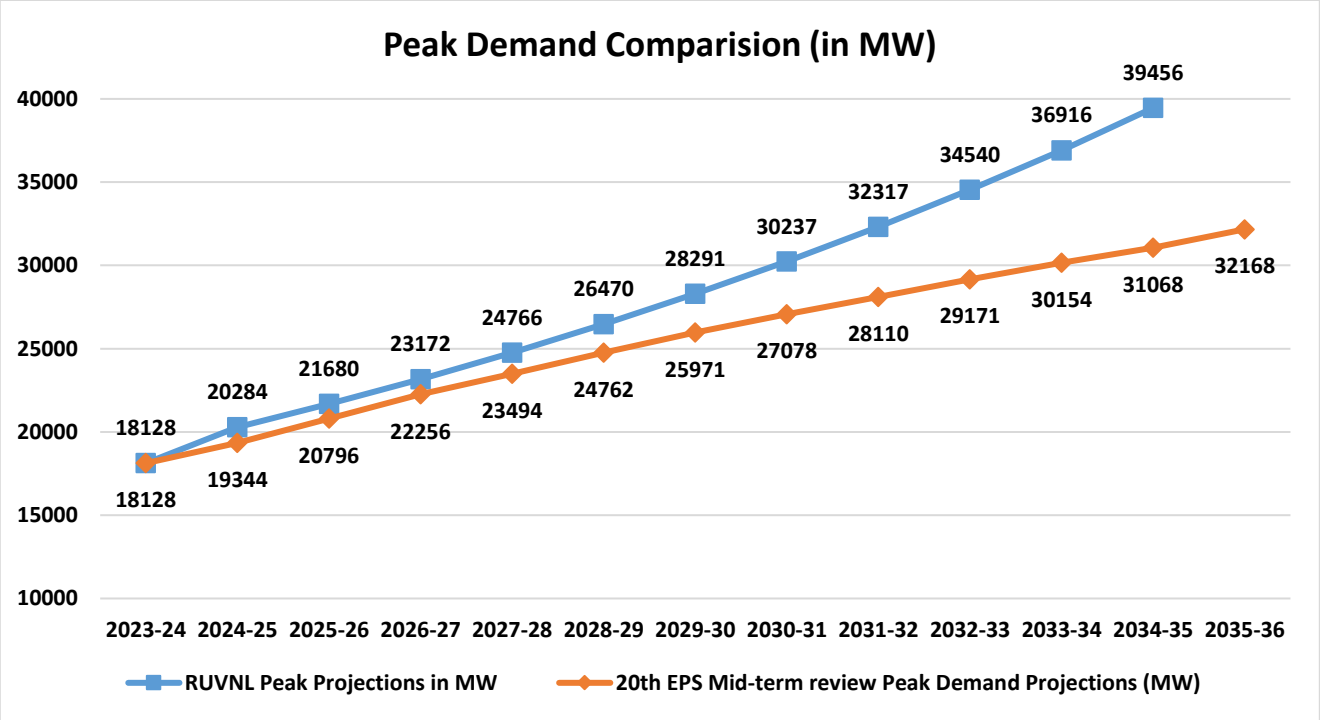


Figure 6 Comparison of Peak Demand Projections of 20th EPS mid-term vs RUVNL

The actual peak load for 2024-25, as per the Peak Power Supply Position (Apr 2024 to Mar 2025) report, stands at 19,165 MW, which closely aligns with the 20th EPS mid-term review peak load estimate of 19,344 MW. In contrast, the peak load forecast of 20,284 MW projected by RUVNL for the 2024-25 appears significantly higher than the observed trends. Additionally, RUVNL's assumption of a flat annual growth rate of 6.9% in peak demand (MW) until 2034-35 seems unlikely. To avoid overestimation of capacity contracts based on RUVNL's projections, the peak demand projections from the 20th EPS mid-term review have been considered.

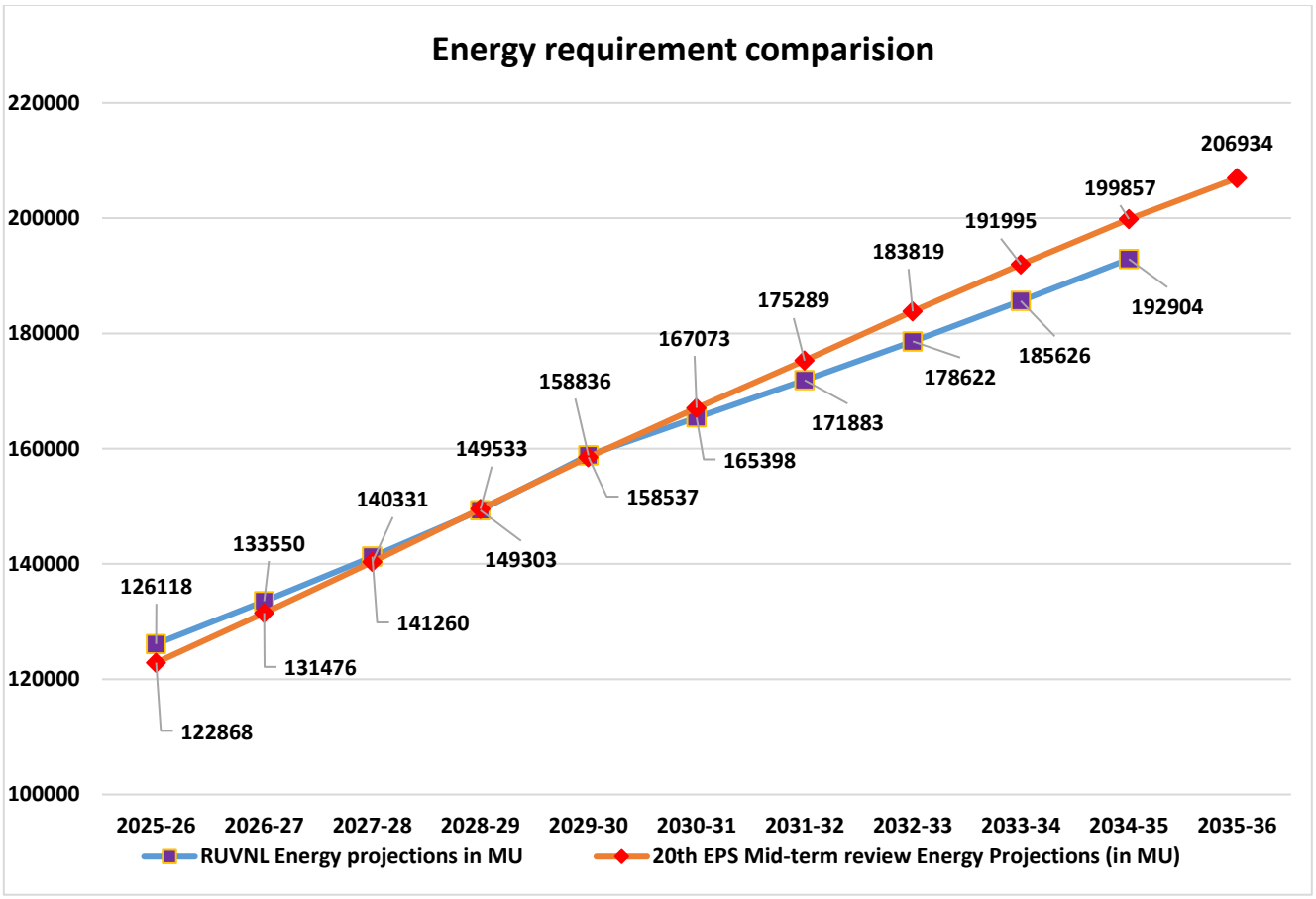


Figure 7 Comparison of Energy Requirement Projections of 20th EPS mid-term vs RUVNL

The energy requirement projections are generally aligned, RUVNL's forecast indicates a slower growth rate beyond 2030-31. Assuming a steady growth trajectory for the utility, the energy requirement projections from the 20th EPS mid-term review have therefore been considered.

ii) Future demand profile till the year 2035-36 has been projected using the demand profile for the year 2022-23 and 2023-24 as the base profile.

iii) The actual solar, wind and hydro generation profiles and CUFs have been referred from National Electricity Plan 2023 (Vol I Generation).

iv) The capital costs of candidate plants for coal, wind, solar, and battery technologies is detailed in the Annexure and are aligned with current market trends and recent price discovery.

v) The planned capacity has been considered based on the tie-up information available with the CEA and as furnished by RUVNL.

Table 4 Source wise planned capacity addition

FY	COAL	NUCLEAR	BIOMASS	HYDRO	SOLAR	PSP	Battery (MW/ MWh)	DRE Solar
2025/26	140	700	30	86	3090	100	245/1470	3000
2026/27	-	-	-	93	-	-	500/1000	7324
2027/28	-	-	-	37	-	-	-	4000
2028/29	-	-	-	0	-	-	-	-
2029/30	2395	-	-	56	-	-	-	-
Total	**2535**	**700**	**30**	**272**	**3090**	**100**	**745/2470**	**14324**

vi) **Renewable Purchase Obligation (RPO) trajectory**: Ministry of Power gazette notification dated 20th October, 2023 had notified the source wise minimum share of consumption of non-fossil sources (renewable energy) by designated consumers, till the year 2029-30.

Table 5 Renewable Purchase Obligation (RPO) trajectory as per MoP order

Sl. No.	Year	Wind renewable energy	Hydro renewable energy	Other renewable energy	Distributed renewable energy	Total renewable energy
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	2024-25	0.67	0.38	27.35	1.5	29.91
2.	2025-26	1.45	1.22	28.24	2.1	33.01
3.	2026-27	1.97	1.34	29.94	2.7	35.95
4.	2027-28	2.45	1.42	31.64	3.3	38.81
5.	2028-29	2.95	1.42	33.1	3.9	41.36
6.	2029-30	3.48	1.33	34.02	4.5	43.33

Further, in view of the country's energy transition goals as well as the long term net zero target of 2070, it is estimated that the share of RE generation in the generation mix will continue to proportionally increase beyond 2029-30. Therefore, the RPO trajectory is assumed to rise steadily beyond 2029-30. Hence, the suggested trajectory of Renewable Purchase Requirement up to FY 2035–36 is presented in the table below:

Table 6 Renewable Purchase Obligation (RPO) trajectory considered for the study

Sl. No.	Year	Wind renewable energy	Hydro renewable energy	Other renewable energy	Distributed renewable energy	Total renewable energy
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	2024-25	0.67	0.38	27.35	1.5	29.91
2.	2025-26	1.45	1.22	28.24	2.1	33.01
3.	2026-27	1.97	1.34	29.94	2.7	35.95
4.	2027-28	2.45	1.42	31.64	3.3	38.81
5.	2028-29	2.95	1.42	33.1	3.9	41.36
6.	2029-30	3.48	1.33	34.02	4.5	43.33
7.	2030-31	40.5			5	45.5
8.	2031-32	41.5			5.5	47
9.	2032-33	42.3			6	48.3
10.	2033-34	43			6.5	49.5
11.	2034-35	43.5			7	50.5
12.	2035-36	44			7.5	51.5

Based on the trajectory specified, RPO quantum in million units (MUs) from hydro, wind, other (Solar, biomass etc.) and distributed renewable energy (DRE) is calculated and tabulated below:

Table 7 Total Energy required to meet RPO (MU)

Sl. No.	Year	Wind renewable energy (MU)	Hydro renewable energy	Other renewable energy	Distributed renewable energy	Total renewable energy
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	**2025-26**	1781.59	1498.99	34697.92	2580.23	40558.73
2.	**2026-27**	2590.08	1761.78	39363.91	3549.85	47265.62
3.	**2027-28**	3438.11	1992.70	44400.73	4630.92	54462.46
4.	**2028-29**	4411.22	2123.37	49495.42	5831.79	61846.85
5.	**2029-30**	5517.09	2108.54	53934.29	7134.17	68694.08
6.	**2030-31**	67664.57			8353.65	76018.22
7.	**2031-32**	72744.94			9640.90	82385.83
8.	**2032-33**	77755.44			11029.14	88784.58
9.	**2033-34**	82557.85			12479.68	95037.53
10.	**2034-35**	86937.80			13989.99	100927.79
11.	**2035-36**	91050.96			15520.05	106571.01

Table 8 Renewable Energy Deficit/Surplus

FY	RE Generation required to meet RPO	RE Generation required to meet RPO	RE Generation available/met (From existing/ planned contracts)	RPO met (%)	RPO Surplus(+)/ Deficit (-)
	(MU)	(%)	(MU)	(%)	(%)
2025/26	40558.73	33.01%	41803	34.02%	1.01%
2026/27	47265.62	35.95%	54287	41.29%	5.34%
2027/28	54462.46	38.81%	60981	43.45%	4.64%
2028/29	61846.85	41.36%	61050	40.83%	-0.53%
2029/30	68694.08	43.33%	61272	38.65%	-4.68%
2030/31	76018.22	45.50%	61272	36.67%	-8.83%
2031/32	82385.83	47.00%	61272	34.95%	-12.05%
2032/33	88784.58	48.30%	61272	33.33%	-14.97%
2033/34	95037.53	49.50%	61272	31.91%	-17.59%
2034/35	100927.79	50.50%	61272	30.66%	-19.84%
2035/36	106571.04	51.50%	61272	29.61%	-21.89%

As indicated in the tables above, the state will not be able to meet its RPO requirements from 2028-29 onwards based on their existing and planned contracts additions envisaged.

7.0 Outcome of the model

7.1 Unserved Energy Projections

Initially, the study is conducted considering only the existing and planned capacity contracts. The total unserved energy for the year 2035-36 is arrived at 35,835 MU. The year-wise likely unserved energy with the planned capacities is given in the figure.

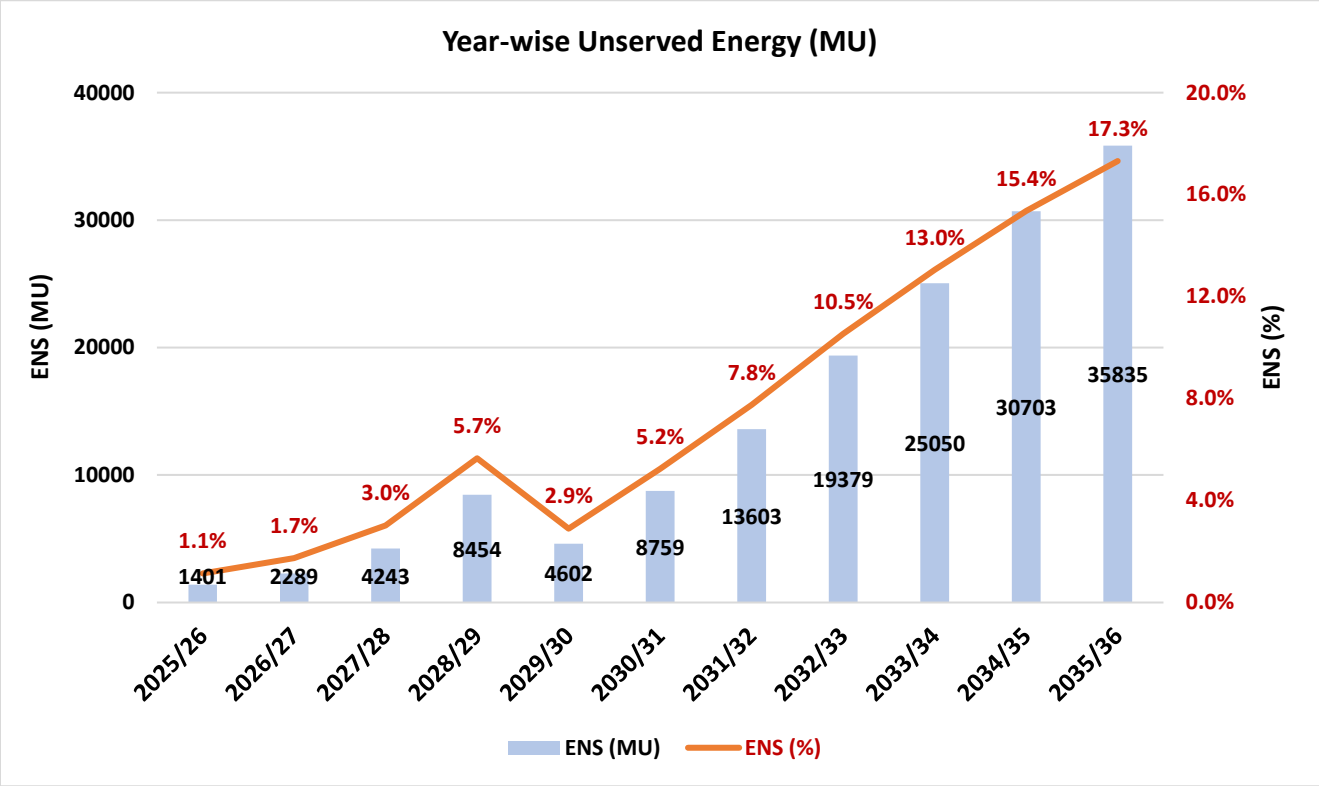


Figure 8 Yearly likely unserved energy (in MU) with the existing and planned capacities

The study has also analyzed the daily and monthly pattern of unserved energy in the year 2035-36, it can be seen that contracted capacity (present and planned) is unable to meet the demand.

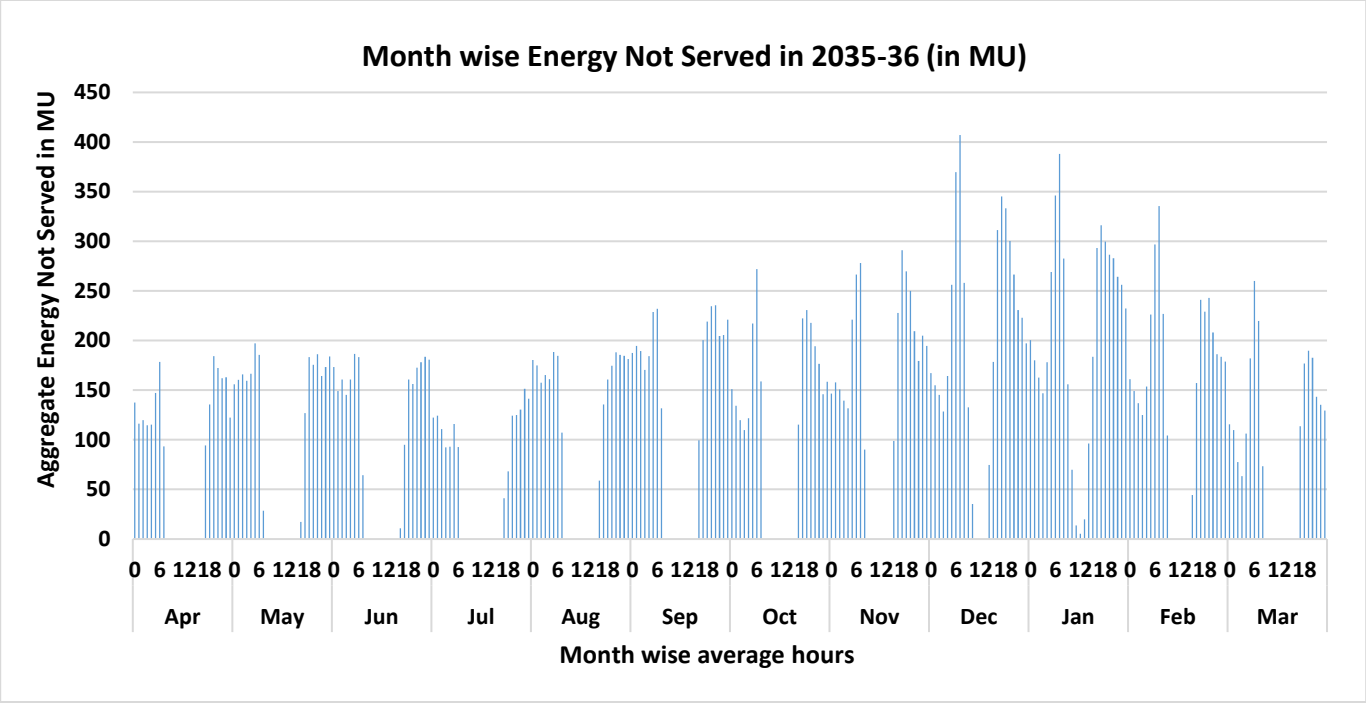


Figure 9 Block-wise Unserved Energy Pattern GWh (2035-36)

The unmet demand occurs mainly during non-solar hours throughout the year. Additionally, the state is expected to face unmet demand even during solar hours in January and February, when electricity demand is higher compared to other months.

7.2 Investment options to meet the unserved energy

To meet this unserved energy, energy investment options (i.e., candidate capacities) are given to the model to find the least cost optimal capacity mix required to meet the demand with RPO obligations.

The capacity projections for RUVNL are given below:

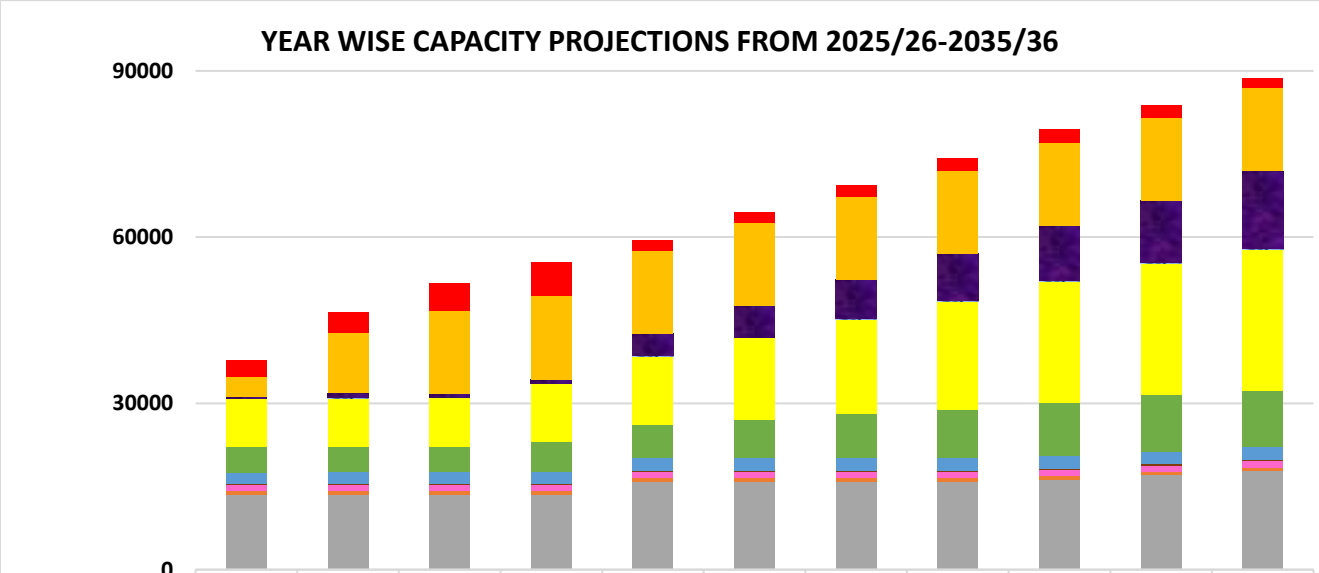
Table 9 Year-wise contracted capacity projections (in MW)

Year	Coal	Gas	Nuclear	Biomass	Hydro	Wind	Solar	DRE	PSP	Battery (MW/MWh)	MTOA/ STOA
2025/26	13565	601	1157	212	2048	4566	8713	3678	100	245/1470	2954
2026/27	13565	601	1157	212	2141	4566	8713	11002	100	745/2470	3667
2027/28	13565	601	1157	212	2178	4566	8713	15002	100	745/2470	4882
2028/29	13565	601	1157	212	2178	5316	10513	15002	100	745/2470	6029
2029/30	15960	601	1157	212	2234	6066	12313	15002	100	3956/18273	1823
2030/31	15960	601	1157	212	2234	6966	14713	15002	100	5676/26416	1962
2031/32	15960	601	1157	212	2234	7866	17113	15002	100	7119/34471	2050
2032/33	15960	601	1157	212	2234	8766	19513	15002	100	8429/41193	2289
2033/34	16264	601	1157	212	2234	9666	21913	15002	100	9887/47463	2379
2034/35	17064	601	1157	212	2234	10266	23713	15002	100	11223/52807	2224
2035/36	17864	601	1157	212	2234	10266	25513	15002	100	13984/63851	1687

The technology wise battery projection (in MW/MWh) is given below:

Year	Bat_2h	Bat_4h	Bat_6h
2025/26	0/0	0/0	245/1470
2026/27	500/1000	0/0	245/1470
2027/28	500/1000	0/0	245/1470
2028/29	500/1000	0/0	245/1470
2029/30	500/1000	1731/6927	1724/10345
2030/31	500/1000	2822/11290	2354/14126
2031/32	500/1000	3121/12485	3497/20986
2032/33	500/1000	3690/14762	4238/25431
2033/34	500/1000	4929/19718	4457/26745
2034/35	500/1000	6265/25062	4457/26745
2035/36	500/1000	9026/36106	4457/26745

The projected contracted capacity mix, year-wise is given in the figure below:



	2025/26	2026/27	2027/28	2028/29	2029/30	2030/31	2031/32	2032/33	2033/34	2034/35	2035/36
MTOA/ STOA	2954	3667	4882	6029	1823	1962	2050	2289	2379	2224	1687
DRE	3678	11002	15002	15002	15002	15002	15002	15002	15002	15002	15002
BATTERY	245	745	745	745	3956	5677	7119	8429	9887	11223	13984
PSP	100	100	100	100	100	100	100	100	100	100	100
SOLAR	8713	8713	8713	10513	12313	14713	17113	19513	21913	23713	25513
WIND	4566	4566	4566	5316	6066	6966	7866	8766	9666	10266	10266
HYDRO	2048	2141	2178	2178	2234	2234	2234	2234	2234	2234	2234
BIOMASS	212	212	212	212	212	212	212	212	212	212	212
NUCLEAR	1157	1157	1157	1157	1157	1157	1157	1157	1157	1157	1157
GAS	601	601	601	601	601	601	601	601	601	601	601
COAL	13565	13565	13565	13565	15960	15960	15960	15960	16264	17064	17864

Figure 10 Projected Contracted Capacity Mix Year-wise (MW)

The STOA/MTOA requirement can be fulfilled through power procurement from markets or bilateral agreements. The STOA/MTOA value reflects the peak value requirement and seasonal banking requirements in terms of MW.

Reliability studies have been conducted based on the projected capacity for the year 2035-36. The analysis confirms that the projected capacity meets the reliability criteria specified in the National Electricity Plan (NEP), with the Loss of Load Probability (LoLP) and Not-Served Energy (NENS) remaining within the permissible limits of 0.2% and 0.05%, respectively (as specified in the National Electricity Plan (NEP)).

As per the Resource Adequacy studies, the likely total projected contracted capacity for the year 2035-36 is around 86,933 MW which consists of 7864 MW from coal, 601 MW from gas, 1157 MW from nuclear, 212 MW from biomass, 2234 MW from hydro, 10266 MW from wind, 25513 MW from solar, 15002 MW from Distributed Renewable Energy (DRE) sources, 100 MW of PSP, 13984 MW/63851 MWh from Battery Energy Storage System (BESS). Further, in addition to this, 1687 MW of MTOA/STOA arrangement will be required. This capacity shall be able to meet the projected demand with prescribed reliability criteria.

It is important to note that any deviations in the commissioning schedule of the planned capacity could result in a situation where the state is unable to meet the projected peak demand and energy requirements identified in this study with the available resources. Such changes may also lead to an increase in the cost of reliably meeting the state’s power demand.

The Planning Reserve Margin (PRM) for RUVNL has been assessed at 37% during solar hours and 5% during non-solar hours. Furthermore, the projected/contracted capacity is in compliance with the stipulated Renewable Purchase Obligation (RPO) targets.

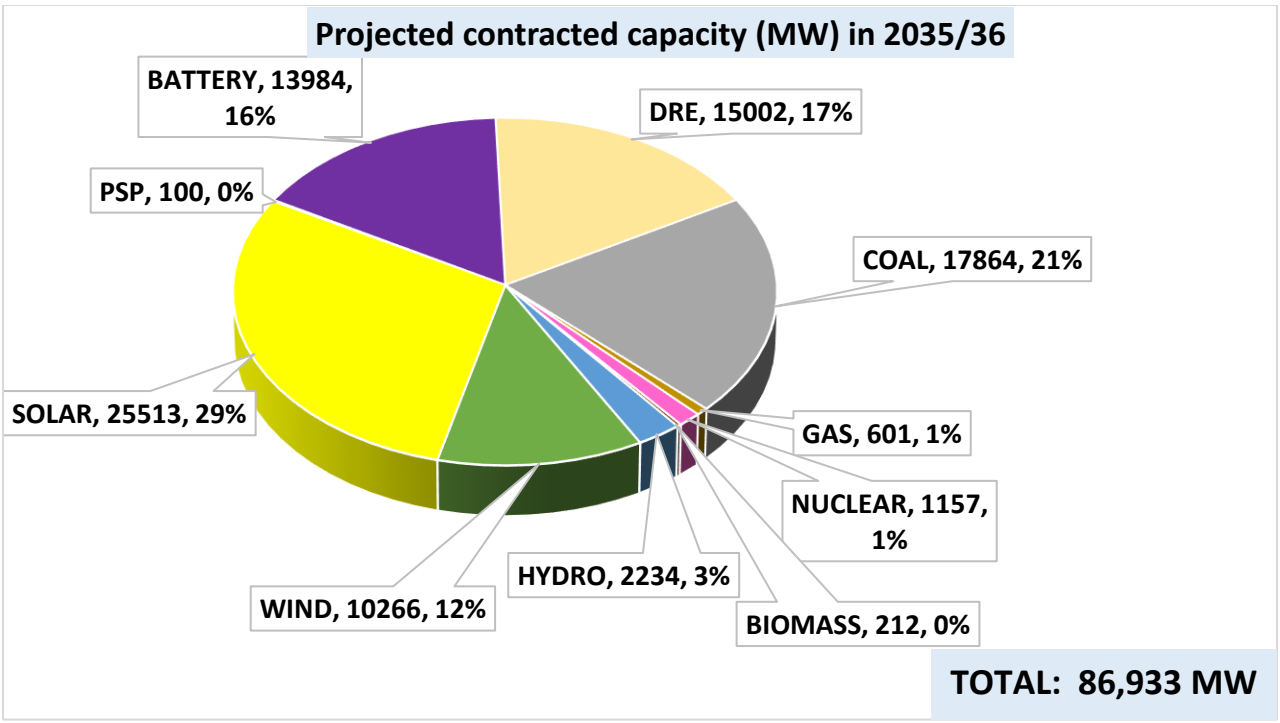


Figure 11 Contracted Capacity Mix in 2035-36 with PRM of 37% during solar hours and 5% during non-solar hours

As per the study the utility needs to contract following capacities (planned and additional) per year till 2035-36 to meet its demand reliably.

Table 10 Year wise Capacity Addition (in MW)

	COAL		NUCLEAR	BIOMASS	HYDRO	WIND
Year	**Planned Contracts**	**Additional Requirement**	**Planned Contracts**	**Planned Contracts**	**Planned Contracts**	**Additional Requirement**
2025/26	140	0	700	30	86	0
2026/27	0	0	0	0	93	0
2027/28	0	0	0	0	37	0
2028/29	0	0	0	0	0	750
2029/30	2395	0	0	0	56	750
2030/31	0	0	0	0	0	900
2031/32	0	0	0	0	0	900
2032/33	0	0	0	0	0	900
2033/34	0	305	0	0	0	900
2034/35	0	800	0	0	0	600
2035/36	0	800	0	0	0	0
TOTAL	**2535**	**1905**	**700**	**30**	**272**	**5700**
	SOLAR		**PSP**	**Battery (MW/MWh)**		**Distributed RE**
Year	**Planned Contracts**	**Additional Requirement**	**Planned Contracts**	**Planned Contracts**	**Additional Requirement**	**Planned contracts**
2025/26	3090	0	100	245/1470	0/0	3000
2026/27	0	0	0	500/1000	0/0	7324
2027/28	0	0	0	0	0/0	4000
2028/29	0	1800	0	0	0/0	0
2029/30	0	1800	0	0	3211/15803	0
2030/31	0	2400	0	0	1720/8143	0
2031/32	0	2400	0	0	1442/8055	0
2032/33	0	2400	0	0	1310/6722	0
2033/34	0	2400	0	0	1458/6269	0
2034/35	0	1800	0	0	1335/5343	0
2035/36	0	1800	0	0	2761/11044	0
TOTAL	**3090**	**16800**	**100**	**745/2470**	**13239/61381**	**14324**

The year wise battery addition (in MW/ MWh) details is given below:

Year	Bat_2h	Bat_4h	Ba_6h	
	Planned	Additional Requirement	Planned	Additional Requirement
2025/26	0/0	0/0	245/1470	0/0
2026/27	500/1000	0/0	0/0	0/0
2027/28	0/0	0/0	0/0	0/0
2028/29	0/0	0/0	0/0	0/0
2029/30	0/0	1731/6927	0/0	1479/8875
2030/31	0/0	1090/4362	0/0	630/3780
2031/32	0/0	298/1195	0/0	1143/6859
2032/33	0/0	569/2277	0/0	740/4445
2033/34	0/0	1239/4956	0/0	218/1313
2034/35	0/0	1335/5343	0/0	0/0
2035/36	0/0	2761/11044	0/0	0/0
TOTAL	**500/1000**	**9026/36106**	**245/1470**	**4212/25275**

The year on year RE capacity requirement required to fulfil the utility's RPO is tabulated below:

Table 11 Source wise Contract addition for RPO fulfilment as estimated by Model

FY	BIOMASS	HYDRO	WIND	SOLAR		DRE Solar
	Planned	Planned	Additional Contract	Planned	Additional Contract	Planned
2025/26	30	86	-	3090	-	3000
2026/27	-	93	-	-	-	7324
2027/28	-	37	-	-	-	4000
2028/29	-	0	750	-	1800	-
2029/30	-	56	750	-	1800	-
2030/31	-	-	900	-	2400	-
2031/32	-	-	900	-	2400	-
2032/33	-	-	900	-	2400	-
2033/34	-	-	900	-	2400	-
2034/35	-	-	600	-	1800	-
2035/36	-	-	0	-	1800	-
Total	**30**	**272**	**5700**	**3090**	**16800**	**14324**

The share of non-fossil fuel based capacity in the generation mix is projected to increase to around 75% by 2035-36 from 49% in 2024-25. The projected gross generation mix for the state is shown in figure:

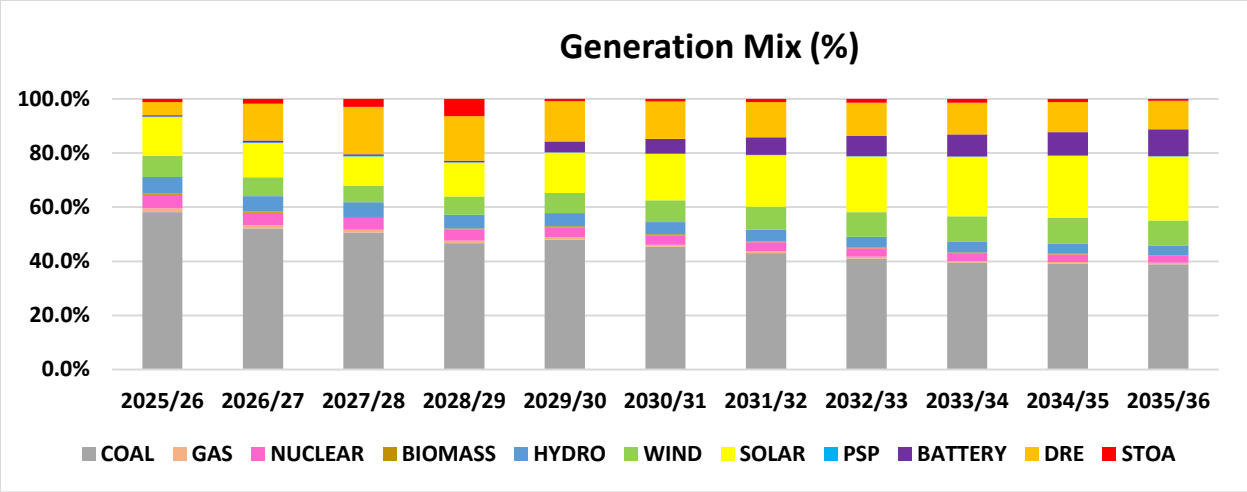
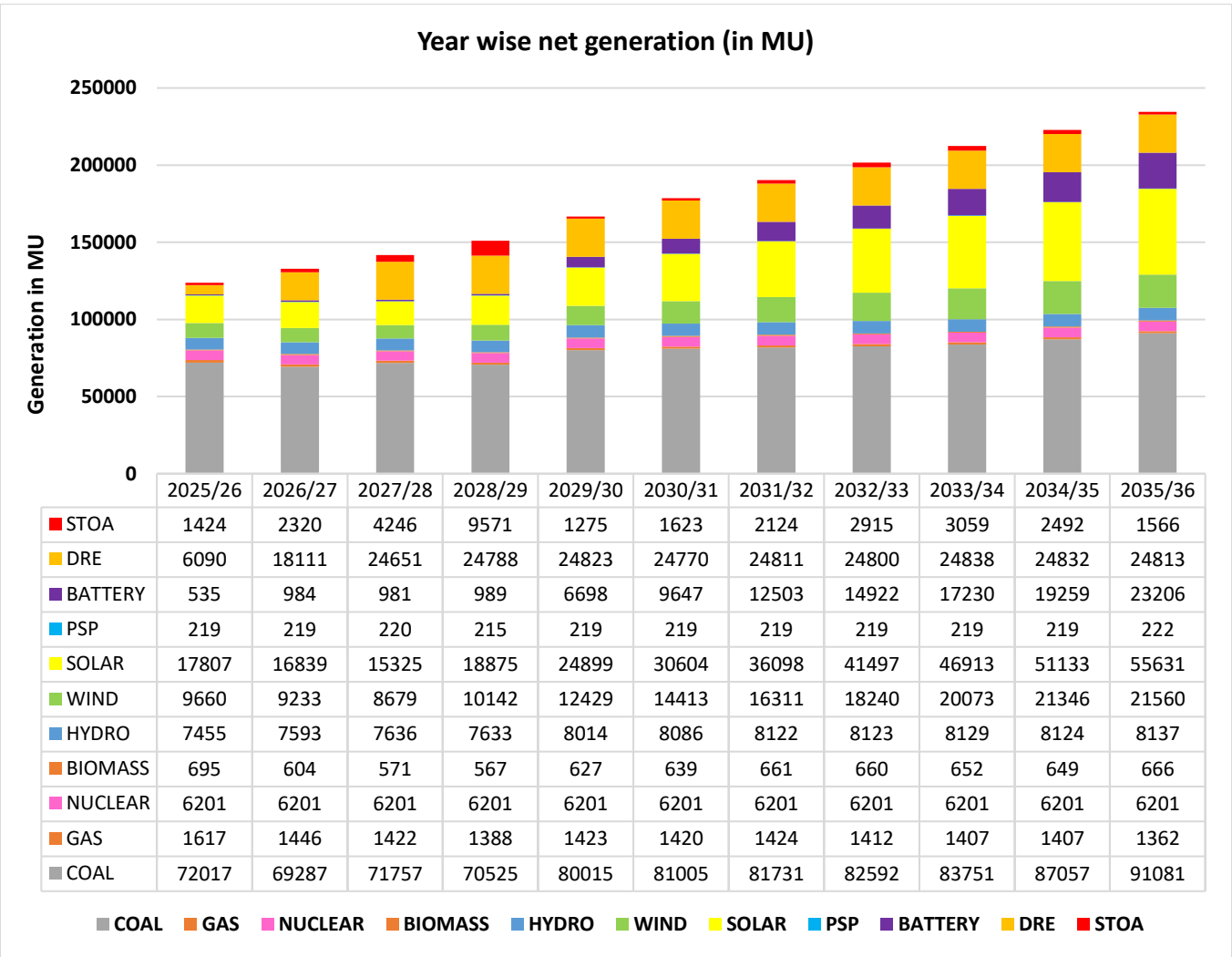


Figure 12 Year-wise projected gross generation mix (in %)

The share of non-fossil based generation will be around 50% in the year 2035-36.



	2025/26	2026/27	2027/28	2028/29	2029/30	2030/31	2031/32	2032/33	2033/34	2034/35	2035/36
STOA	1424	2320	4246	9571	1275	1623	2124	2915	3059	2492	1566
DRE	6090	18111	24651	24788	24823	24770	24811	24800	24838	24832	24813
BATTERY	535	984	981	989	6698	9647	12503	14922	17230	19259	23206
PSP	219	219	220	215	219	219	219	219	219	219	222
SOLAR	17807	16839	15325	18875	24899	30604	36098	41497	46913	51133	55631
WIND	9660	9233	8679	10142	12429	14413	16311	18240	20073	21346	21560
HYDRO	7455	7593	7636	7633	8014	8086	8122	8123	8129	8124	8137
BIOMASS	695	604	571	567	627	639	661	660	652	649	666
NUCLEAR	6201	6201	6201	6201	6201	6201	6201	6201	6201	6201	6201
GAS	1617	1446	1422	1388	1423	1420	1424	1412	1407	1407	1362
COAL	72017	69287	71757	70525	80015	81005	81731	82592	83751	87057	91081

Figure 13 Year-wise projected gross generation (in GWh)

7.3 Coal Capacity Performance

The coal capacity PLF is expected to remain in the range of around 60% - 58% for the years till 2036 ensuring higher absorption increasing contracts from renewable energy.

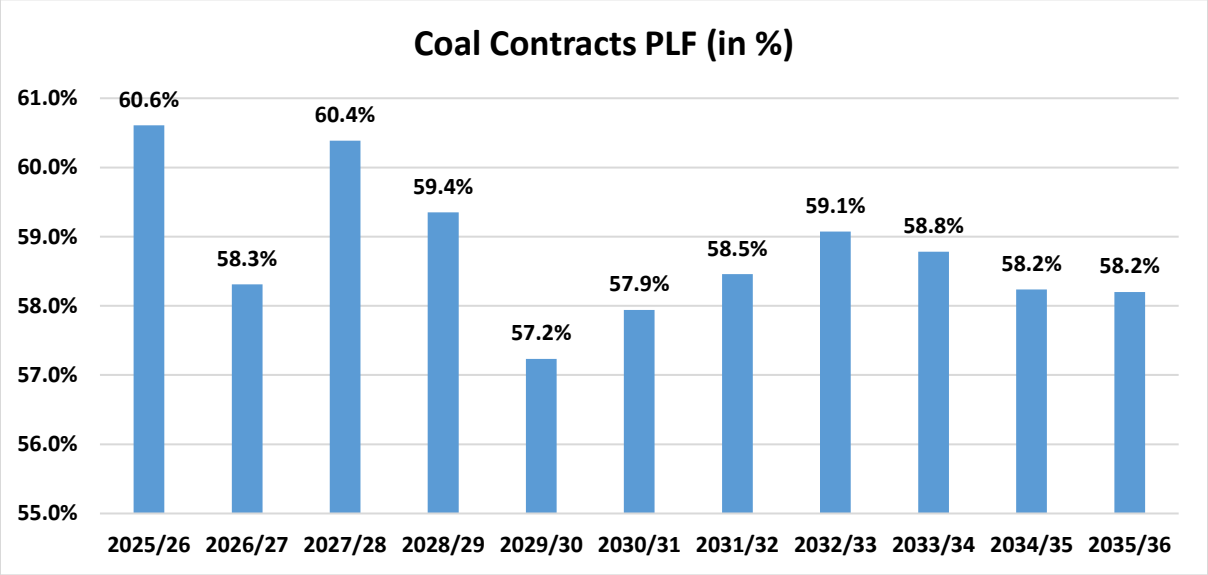


Figure 14 Year-wise coal contracts PLF (in %)

7.4 Day-wise Surplus Coal Capacity (in MW)

Surplus capacity is available with the state due to RE availability, Demand variation etc. The pattern of surplus capacities has been observed as below. This capacity can be shared with other states/ Discoms and reduce the fixed cost burden on the utilities resulting in reduction in the cost for consumer. The utility has likely surplus capacity available during April to July months of around 550 MW in 2028-29 as shown below which can be shared with other states/ Discoms.

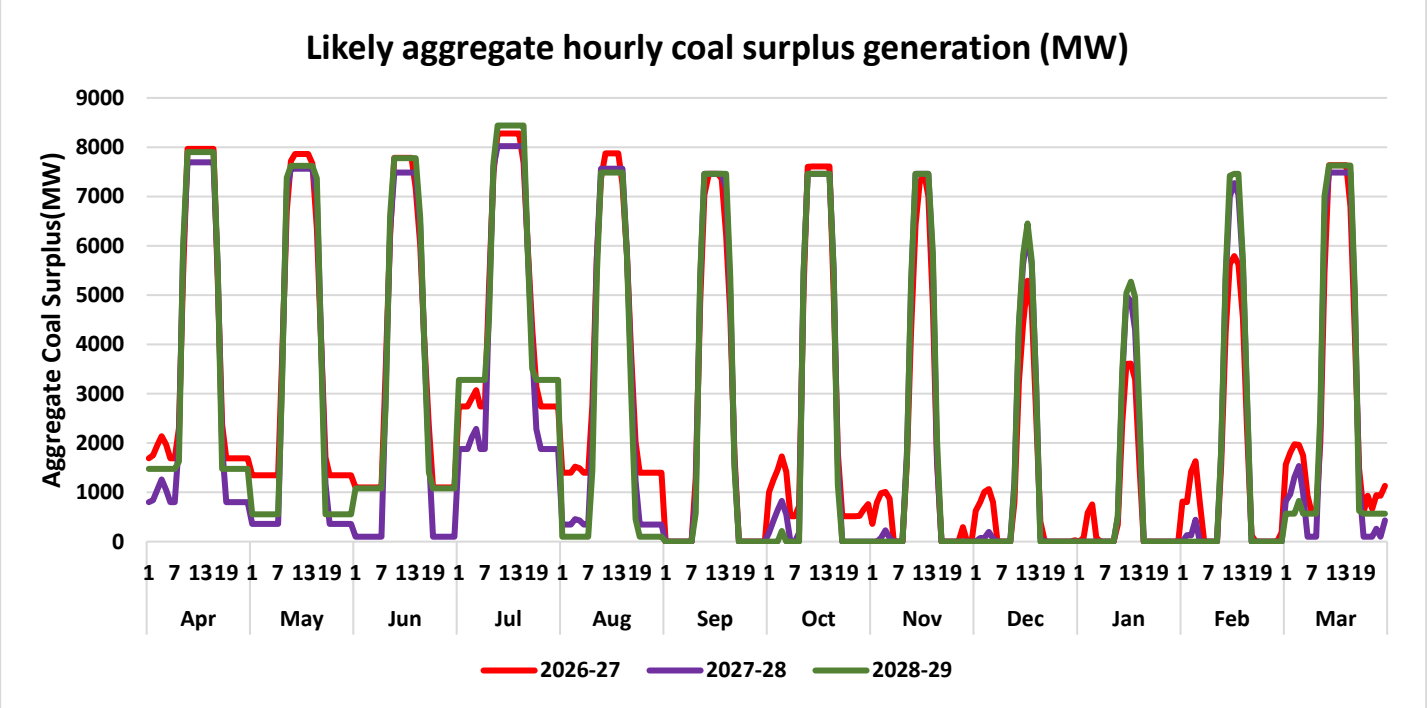


Figure 15 Surplus Coal Capacity Year-wise (MW)

8.0 Conclusion

Based on the Resource Adequacy studies of Rajasthan up to the year 2035-36, the following conclusions may be drawn:

1. The study has been done based on the hourly load pattern of the year 2022-23 and 2023-24. Based on the demand pattern, it is seen that the peak demand season is typically from January and February with peak demand occurring during solar hours (generally between 12 noon to 3 PM).
2. The study has considered energy requirement projections as per the projections of the 20th EPS Mid-term review, which envisages that the annual energy requirement of the state is likely to grow at a CAGR of 5.3% while the peak demand for the utility is likely to grow at a CAGR of 4.5% for the period of 2024-25 to 2035-36.

3. Rajasthan is likely to witness energy deficit ranging from 1.4 to 36 BUs in different years from 2024-25 to 2034-35 with the existing and planned capacity addition only.
4. The state is likely to have unserved energy in coming years and need to contract fossil-based capacities for meeting energy requirements other than the planned capacities. Additional coal-based capacities has to be procured of about 1905 MW by the year 2035-36. In addition to this, the state will likely require MTOA/ STOA arrangement ranging from around 1500 MW to 6000 MW in different years as outlined in the report. The STOA/MTOA requirement can be fulfilled through power procurement from markets or bilateral agreements. The STOA/MTOA value reflects the peak value requirement and seasonal banking requirements in terms of MW.
5. The projected capacity and generation mix outlined in the report meet the utility's RPO requirements for the years 2025-26 to 2035-36.
6. The Planning Reserve Margin (PRM) for Rajasthan has been assessed at 37% during solar hours and 5% during non-solar hours. Further, the study indicates year-wise short-term/medium-term/bilateral requirements to meet the demand optimally.
7. The current capacity mix of the utility has 51% of contracted capacity from fossil fuel sources. The share of fossil fuel based capacity is likely to reduce to 25.3% in 2035-36. In 2035-36, the RE based generation (that includes hydro, solar, wind, biomass and DRE) capacity are likely to constitute around 73% of the total installed capacity.
8. It is likely that RUVNL may have surplus capacity available during the months from April to July which can be shared with other utilities/states through banking / bilateral arrangements including Pushp portal.
9. Accurate demand assessment is fundamental to capacity expansion modelling and directly impacts the Resource Adequacy (RA) study outcomes. To achieve realistic and data-driven results, States are strongly encouraged to adopt scientific tools and robust methodologies for demand forecasting.
10. Timely commissioning of planned capacities is critical to ensuring that the state can meet the projected peak demand and energy requirements identified in this study. Any deviation from the planned schedule may lead to resource shortfalls and could significantly increase the cost of reliably meeting the state’s power demand.

Annexure

Planned Future Contracted (MW) considered in the study

Sr. No.	Tied capacity name	Type of generation	Expected COD	RUVNL share (in MW)
1.	Khurja	Coal	2025-26	140
2.	RAPP 7 and 8	Nuclear		700
3.	Biomass Planned	Biomass		30
4.	Parbati HEP II	Hydro		86
5.	AP Solar	Solar		490
6.	Rajasthan Solar	Solar		2600
7.	Tehri PSP	PSP		100
8.	AP Energy Storage	BESS		245 MW/ 1470 MWh
9.	Subansiri	Hydro	2026-27	93
10.	Battery Planned	BESS		500 MW/ 1000 MWh
11.	Vishnugad Pipalkoti	Hydro	2027-28	37
12.	Chhabra Unit 7 & 8	Coal	2029-30	1320
13.	Gurha	Coal		125
14.	Kalisindh	Coal		800
15.	Singrauli stage III	Coal		150
16.	Tapovan Vishnugad	Hydro		56

Assumption for Resource Adequacy Studies

1. Electricity Demand & peak requirement: As per projections in 20th EPS Mid-term review.
2. Demand Profile: Based on hourly demand profile of 2023-24 and 2022-23.
3. Existing & Planned Capacity: As per the information shared by the utility.
4. Cost parameters: based on information in National Electricity Plan.

RE CUF considered

Hydro	Wind	Solar	DRE
44-48 %	26%	25%	19%

Technical Parameters

Technology	Type	Availability (%)	Ramping (%/min)	Min. Technical . (%)	Start -up time (hr)		
					Hot	Warm	Cold
Coal/ Lignite	Existing/Planned	85	1	55	2	5	10
	Candidate	88	1	55	2	5	10
Gas	Existing	90	5	40	1.5	2	3
Nuclear	Existing/Planned	68	Const. Load	-	-	-	-
Biomass	Existing/Planned	60	2	50	2	4	8

Hydro	Existing/Planned/ Candidate	As per available hourly generation profile	100	-	-	-	-
Solar	Existing/Planned		-	-	-	-	-
	Candidate		-	-	-	-	-
Wind	Existing/Planned		-	-	-	-	-
	Candidate		-	-	-	-	-
Pumped storage	Existing/Planned	95	50	-	-	-	-
	Candidate		50	-	-	-	-
Battery Energy Storage	Candidate	98	NA	-	-	-	-

Technology	Type	Heat Rate (MCal/MWh)		Aux. Consum. (%)	Min. online time (hr)	Min. offline time (hr)	Start-up fuel consumption (MCal/MW)		
		At max loading	At min loading				Hot	Warm	Cold
Coal	Existing/ Planned	2300 to 2879	2438 to 3052	7.0	6	4	600	1000	1800
	Candidate (SC & USC)	2060 to 2125	2183 to 2253	6.5	6	4	600	1000	1800
Gas	Existing	2000 to 2900	2260 to 3277	2.5	4	3	30	50	90
Nuclear	Existing/ Planned	2777	2777	10	6	4	-	-	-
	Candidate	2777	2777	10	-	-	-	-	-
Biomass	Existing/ Planned	4200	4450	8	6	4	600	1000	1800
	Candidate	4200	4450	8	6	4	600	1000	1800
Hydro	Existing/ Planned	-	-	0.7	-	-	-	-	-
	Candidate	-	-	0.7	-	-	-	-	-
Pumped Storage	Existing/ Planned	-	-	pump efficiency 80 %	-	-	-	-	-
	Candidate	-	-		-	-	-	-	-
Battery Energy Storage	Candidate	-	-	Round trip losses 12%	-	-	-	-	-

Transmission Parameters

A single node has been considered for the purpose of study with all generating units and demand connected to the node. No transmission bottleneck has been considered for the study. Interstate ATC limit has not been considered in the study.

Financial Parameters

Following cost parameters have been assumed:

Resource	Capex* (in ₹/MW)	O&M Fixed Cost (in ₹/MW)	Construction Time (in years)	Amortization /Life time (in years)
Coal	11.5 Cr	19.54 Lakh	4	25
Solar	5 Cr	1 % of Capex	0.5	25
Wind(Onshore)	8 Cr	1% of Capex	1.5	25
Battery Energy Storage (2-Hour)	5.13 Cr to 3.13 Cr	1 % of Capex	0.5	14
Battery Energy Storage (4-Hour)	8.22 Cr to 4.72 Cr	1 % of Capex	0.5	14
Battery Energy Storage (5-Hour)	9.77Cr to 5.51 Cr	1 % of Capex	0.5	14
Battery Energy Storage (6-Hour)	11.31 Cr to 6.30 Cr	1 % of Capex	0.5	14