Report on Resource Adequacy Plan for the state of Uttarakhand

Government of India
Ministry of Power
Central Electricity Authority

Contents

Executive Summary

The electricity demand for the State of Uttarakhand is increasing with a CAGR of 5.1 % from 2023-24 to 2031-32 as forecasted by 20th EPS. The projections of UPCL also indicate that electricity demand may increase with a CAGR of 3.3 % from 2023-24 to 2029-30. For satisfying resource adequacy i.e., meeting the electricity demand reliably and at affordable cost, the State need 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.

Being a hilly state dependent mainly on Hydro generation, seasonality contributes to the seasonal and diurnal variation of the electricity demand in the state. The electricity demand starts increasing from the month of October and is maximum during the month of January. The demand during the months of November, December, January and February is significantly higher compared to rest of the year. The peak electricity load is generally observed during morning and evening hours during winter season (peak months).

Ministry of Power had notified Electricity (Amendment) Rules in December, 2022. As per Rule 16 of the Electricity (Amendment) Rules, Ministry of Power has notified Resource Adequacy guidelines. As per the Resource Adequacy (RA) Guidelines, Central Electricity Authority is entrusted to prepare Long Term-National Resource Adequacy Plan (LT-NRAP). Further Distribution Utility need to carry out LTDRAP (Long term Distribution License Resource Adequacy Plan) to meet the utility peak and energy requirement reliably.

The government of India has notified RPO till 2029-30 which ensure certain amount of energy consumption to be met from renewable energy sources. However, data received from UPCL makes Uttarakhand a Hydro rich state and thus it meets all its RPO obligations.

The resource adequacy studies to assess the hourly generation dispatch with the existing and planned capacity have been carried out to assess the hourly demand supply gap till 2029-30 for Uttarakhand based on inputs received from UPCL. It was found that the state's likely contracted capacity is not sufficient to meet capacity addition plans for conventional as well as renewable energy sources to meet projected demand.

To find out the least cost option for generation capacity expansion for the period 2023-24 to 2031-32, long-term study for the State of Uttarakhand was 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. The Resource adequacy studies have projected likely optimal capacity mix for future years till 2030 which is able to meet anticipated demand reliably at every instance. Generation capacity expansion pathways have been considered for the long-term study based on the yearly capacity addition plans of the state 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. Additionally, an alternative scenario has been studied wherein the likelihood of Uttarakhand meeting 100% of its power from green sources by 2031-32 was considered.

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 order dated 22nd July 2022 had notified the RPO trajectory for the states. 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 have to contract in addition to its existing/planned capacity to meet their RPO targets.

Resource Adequacy studies has been carried out for Uttarakhand based on the inputs received from UPCL and as per RPO trajectory. The study suggests the optimal resource mix till 2032 taking into account all technical and financial parameters associated with capacities. The study optimizes power purchase on a long-term basis while evaluating resource adequacy for meeting the demand 24 X 7 considering variation in demand, RE generation and forced outages of thermal capacities. The study has also assessed the requirement of Planning Reserve margin for Uttarakhand for catering to above highlighted uncertainties so that demand can be met reliably throughout the year.

2.0 Uttarakhand RA Study

2.1 Present Power Scenario in Uttarakhand

As of August 2022, the total contracted capacity for Uttarakhand is 3533 MW. Out of the total contracted capacity (CC), the share of non-fossil fuel-based CC is 73.4 %.
The fuel-wise contracted capacity as on August 2022 is given in Table and Figure below:

Table 1 Fuel-wise Contracted Capacity as on 31st August, 2022

Source	Contracted Capacity (MW)	Percentage
Coal	523	14.8%
Gas	416	11.8%
Nuclear	46	1.3%
Hydro	2162	61.2%
Solar	386	10.9%
Total	**3533**	**100.0%**

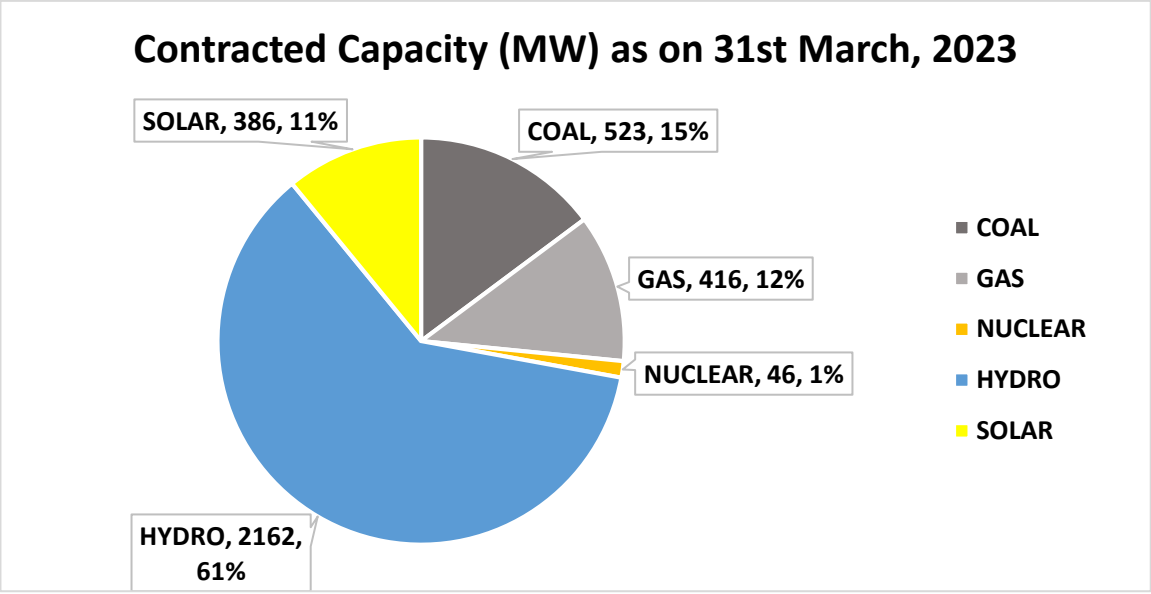

Figure 1 Fuel-wise Contracted Capacity (in MW) as on 31st March, 2023

2.2 Present Demand Analysis (2022-23)

Hourly demand pattern of 2022-23 was analyzed and it was observed that the peak demand for Uttarakhand occurs during the winter months viz December and January. The hourly demand pattern during winter months is significantly different than the rest of the months. Uttarakhand witnesses

peak demand during day hours in the winter months and there is seen to be a significant difference in demand during peak and off peak hours of the day during winter months (October to March) as shown in Figure 2. The difference in the day peak and night peak during the lean demand months of April to September is not much which reflects the effect of seasonality in demand. During the summer months the peak during the day occurs during evening hours, however, during Winter months the demand peaks during the early morning hours (depicted in Figure 3 below). Optimal utilization of resources through short-term contracts like banking or STOA as currently practiced for managing the seasonal variation in demand is one of the effective ways for ensuring resource adequacy in such a case.

The month wise variation in average hourly Demand observed for the year 2022-23 is shown in Exhibit given below:

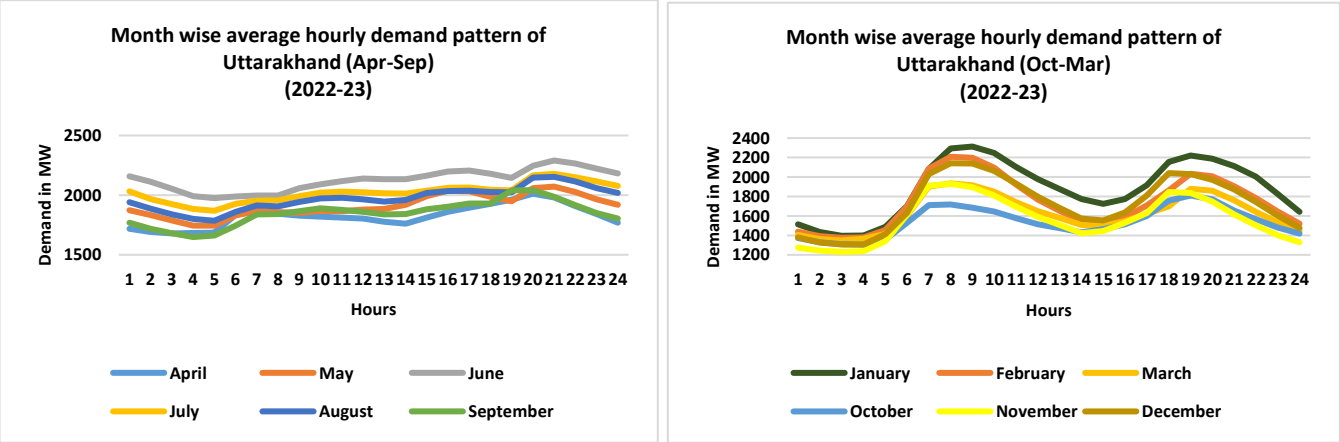

Figure 2 Average Hourly Demand Variation (Month-wise) of Uttarakhand for 2022-23

The variation in Daily Day peak (during Solar hours) vs Night Peak(Non solar hours) observed in the state for the year 2022-23 is shown in the Figure 3 below:

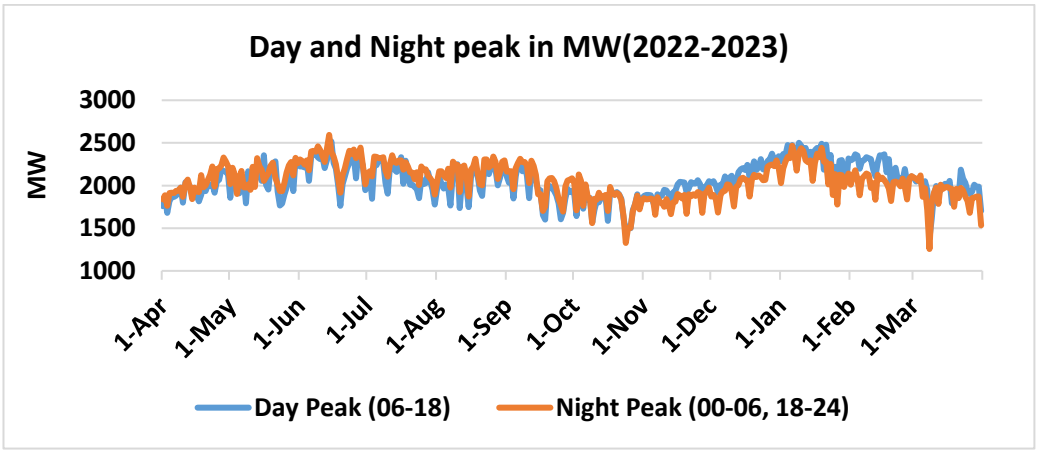

Figure 3 Day and Night Peak in MW of Uttarakhand (2022-23)

3.0 Inputs/Assumptions for the Study

i) The Peak and Energy Demand for the state of Uttarakhand as furnished by the state vis-à-vis 20th EPS (Electric Power Survey) projections is shown in Figure 4 below. As is seen in the Figure 5, the Demand estimation by UPCL were found to be lower than those projected by 20th EPS. Therefore, the Studies have been carried out using 20th EPS projections.

Table 21 Future Demand Projection as per 20th EPS Report

	2022-23	2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32
Energy Projections (MU)	16301 (*)	17138 (*)	18087	19093	20142	21238	22374	23702	24622	25524
Year on Year Growth		5.1%	5.5%	5.6%	5.5%	5.4%	5.3%	5.9%	3.9%	3.7%
Peak Demand Projections (MW)	2603 (2594*)	2742 (*)	2905	3072	3249	3433	3623	3847	4004	4159
Year on Year Growth		5.3%	5.9%	5.7%	5.8%	5.7%	5.5%	6.2%	4.1%	3.9%

*Actual energy consumption and peak demand as per Power Supply Position report of CEA

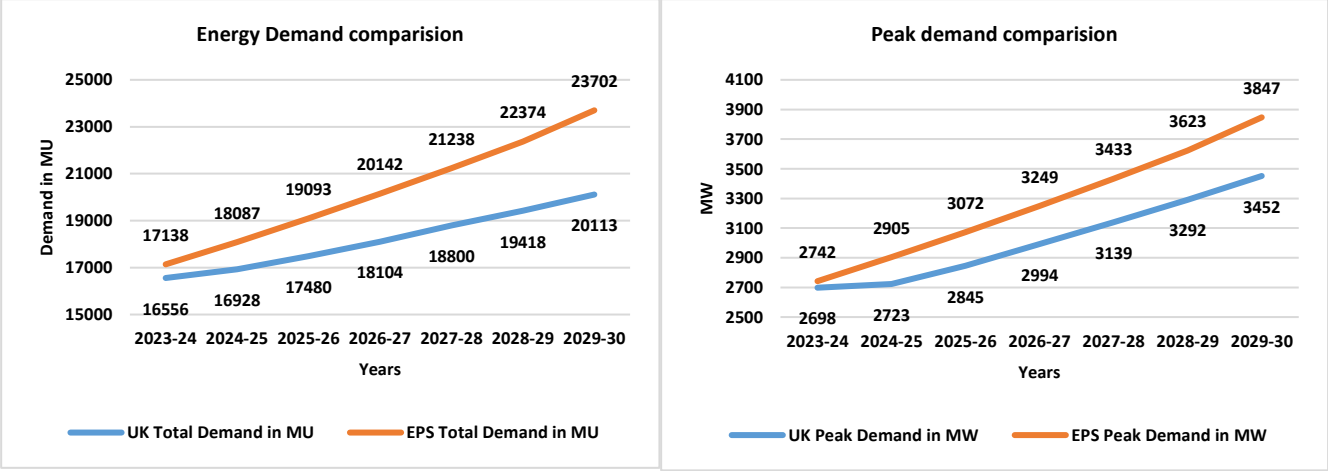

Figure 4 Comparison of Energy Requirement and peak Demand Projections of EPS vs Uttarakhand(Projections from UPCL received only till 2029-30)

Assistance from the Ministry of Power has been recurrently sought by the state to meet its power deficit historically. Ministry of Power allocated unallocated share of Meghalaya (36.29 MW during 18:00 to 22:00 hours and 35.16 MW during the balance period) in NTPC's Bongaigaon Thermal Power Station to Uttarakhand for 1 year from 25.04.2022. Additional 20.70 MW power surrendered by Mizoram in the same power station was allocated to Uttarakhand from 01.05.2022 till 30.04.2023. The state also requested extension of 100 MW unallocated power from Southern Region pool till March 2024 and

an additional 300 MW power from central pool which was extended till 31.03.2023. Also, 300 MW from Northern, Western, and Eastern Regions was allocated to the state till 28.02.2023. It was thus concluded that based on historical precedent of shortage of power in the state, the 20th EPS demand projections for the state, which were seen to be closer to actual demand, ought to be considered for carrying out the RA study. Any suppression of demand may lead to underestimation in capacity requirement and thereby load shedding to consumers.

ii) Future demand profile for the year 2031-32 has been projected using the hourly demand observed in the state during the year 2022-23, as the base profile.

iii) The actual solar and wind generation data (and CUFs) provided by the state have been considered for the Study.

iv) Capital cost of candidate plants for Coal, Wind, Solar, Battery and PSP have been considered as per the National Electricity Plan.

v) Apart from the list of projects likely to yield benefits to the state during the study period as furnished by the state utilities, the projected contracted capacities considered include allocation of 32.53 MW from Rawatbhata APP(RAPP) unit 7 & 8 (2x700 MW) vide M/o Power allocation Order No. 8/23/2002-S.Th. Dated 17th June, 2011 and allocation of 32.53 MW from Gorakhpur Unit 1,2 (2x700 MW) on same lines as per above order.

The year-wise planned capacity addition for the state, as considered for the studies, is summarized in the Table below:

Resource	Y-o-Y Planned Capacity Addition (MW) till 2031-32									
	2023-24	**2024-25**	**2025-26**	**2026-27**	**2027-28**	**2028-29**	**2029-30**	**2030-31**	**2031-32**	**TOTAL**
Coal	0	51.8	0	0	0	0	0	0	0	**51.8**
Nuclear	0	0	0	0	32.53	0	32.53	0	0	**65.06**
Hydro	27	154	6	117	90	336	539	20	0	**1269**
Solar	0	100	0	0	0	0	0	0	0	**100**
PSP	200	0	0	0	0	0	0	0	0	**200**
RTC	100	0	0	0	0	0	0	0	0	**100**
Total	**327**	**305.8**	**6**	**117**	**122.53**	**336**	**571.53**	**20**	**0**	**1805.86**

vi) RPO trajectory: In order to meet its Renewable Purchase Obligation (RPO), as per RPO trajectory notified by the Ministry vide order dated 22nd July, 2022, Uttarakhand needs to add/contract additional renewable capacity (MW) as assessed below.

Table 3 Total Energy required to meet RPO (MU) as per MoP order dated 22.07.2022

Source-wise total Energy required to meet various RPO (MU) as per MoP order dated 22.07.2022							
	2023-24	**2024-25**	**2025-26**	**2026-27**	**2027-28**	**2028-29**	**2029-30**

Hydro RPO	**113**	**195**	**283**	**363**	**457**	**562**	**668**
Wind RPO	**274**	**445**	**642**	**864**	**1111**	**1378**	**1645**
Other RPO	**4252**	**4770**	**5378**	**6014**	**6675**	**7314**	**7957**

Table 4 Generation eligible for RPO (MU) as per existing and planned capacity addition

	2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30
Hydro Generation	**1437**	**2263**	**2272**	**2481**	**2644**	**4308**	**7204**
Wind Generation	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Generation eligible for Other RPO	**7615**	**7798**	**7798**	**7798**	**7798**	**7798**	**7798**

Table 5 Surplus/Shortfall (-) in RPO Generation considering Fungibility for Hydro RPO and Other RPO (MU)

	2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30
Hydro RPO	**1049**	**1623**	**1348**	**1255**	**1077**	**2369**	**4732**
Wind RPO	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Other RPO	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Additional capacity to be contracted by Uttarakhand to meet RPO is given below:

Table 6 As per RPO trajectory, Uttarakhand needs to add/contract following additional capacity (MW).

	2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30	Total
Wind	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Small and large Hydro	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Solar and other RE	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

4.0 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 number 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): The planning reserve margin (PRM) is a metric used by utilities, regulators, or system operators to estimate resource adequacy (i.e., the ability of projected capacity resources to meet projected demand). It is defined as the percentage of projected capacity resources ("firm capacity") above projected peak demand as shown below: -

$$\text{Planning Reserve Margin (PRM)} = \frac{\text{Firm Capacity - Peak demand}}{\text{Peak Demand}}$$

For example, if a region has 12 GW of firm capacity and 10 GW of peak demand, the PRM would be 20%. The PRM is used simply as a metric for comparing the amount of capacity in the system to demand. It is set as a required lower bound to ensure sufficient capacity. The PRM target can be used to ensure new capacity is built in time to meet future demand independent of other market signals.

4.1 Demand variation

The variation in demand pattern of UPCL for last 6 years was analyzed. The hourly demand variation for consecutive years (i.e., 2017-18,2018-19, 2019-20 and 2022-23) has been analyzed. The demand pattern for the years 2020-21 and 2021-22 was ignored due to the unusual variation from other years because of COVID pandemic. The pattern of % variation in hourly demand for the years 2017-18, 2018-19, 2019-20 and 2022-23 is shown below.

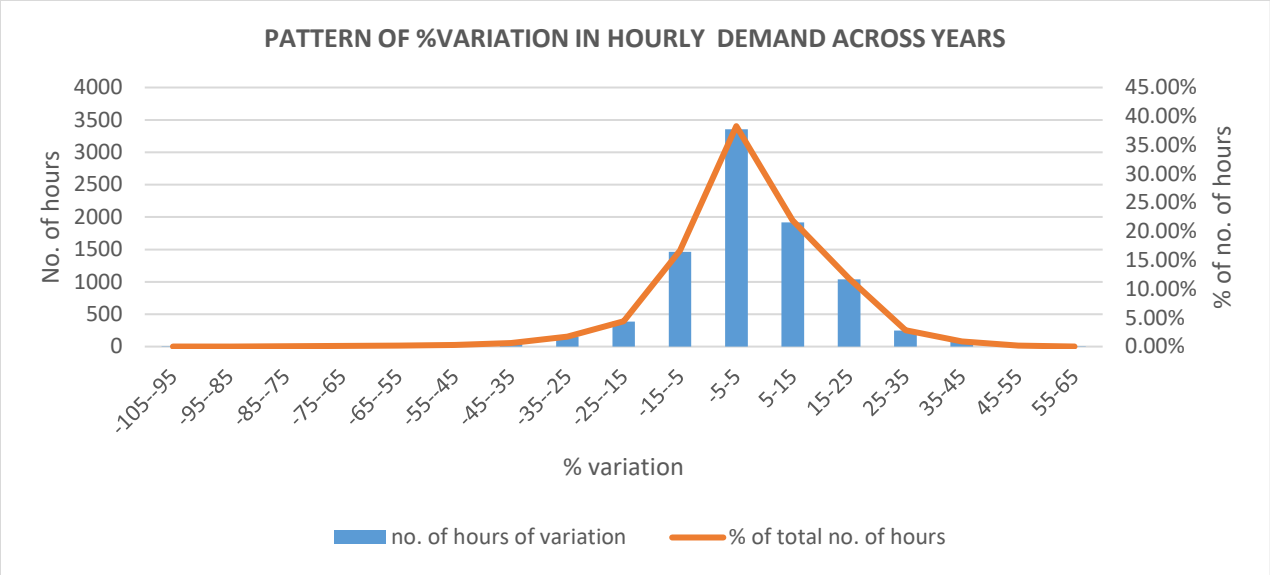

Figure 5 Hourly Variation in Demand across years

It can be observed that the hourly demand typically varies ±15% for 77% of instances and ±10% for 62% of instances from corresponding hour in previous years (normalized figure). This variation is primarily due to temperature, weather parameter or any random outages of transmission line and/or generation units, etc. This variation has been captured in the reliability study by varying the projected hourly demand for the future years in the range of ±15% by introducing a random variable (with normal distribution) for demand as per observed behavior over the years.

4.2 Variation in RE generation

In the Long-term capacity expansion planning studies, a particular profile for Solar and Wind Plants are considered based on the observed solar and wind generation data over the recent years 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 generation and wind generation has been varied by 10% and 50% respectively to incorporate the variation in these generation sources and plan for requisite measures to mitigate such behavior.

4.3 Forced Outages of Thermal Generators

The forced outage rate of thermal generators were observed for previous years and it was observed that average planned outage rate is typically at 10% with ±5% variation. The same has been incorporated in the model.

Based on the aforementioned assumptions, variation were modelled in the system and reliability studies were carried out to ascertain robustness of the system. The LOLP & EENS of the system was found to be within specified range.

5.0 Results of the Resource Adequacy Studies

5.1 Unserved Energy Projections

The study was carried out considering existing capacity, planned capacity & capacity required to fulfil the RPO obligations. It was observed that the total unserved energy in the year 2029-30 is about 1977 MU.

Further, it was analyzed that from the daily and monthly pattern of unserved energy in the year 2029-30 that the unserved energy is likely during the peak demand months when the contracted capacity (present, planned and additional RE addition for meeting RPO obligation) is unable to meet the projected demand.

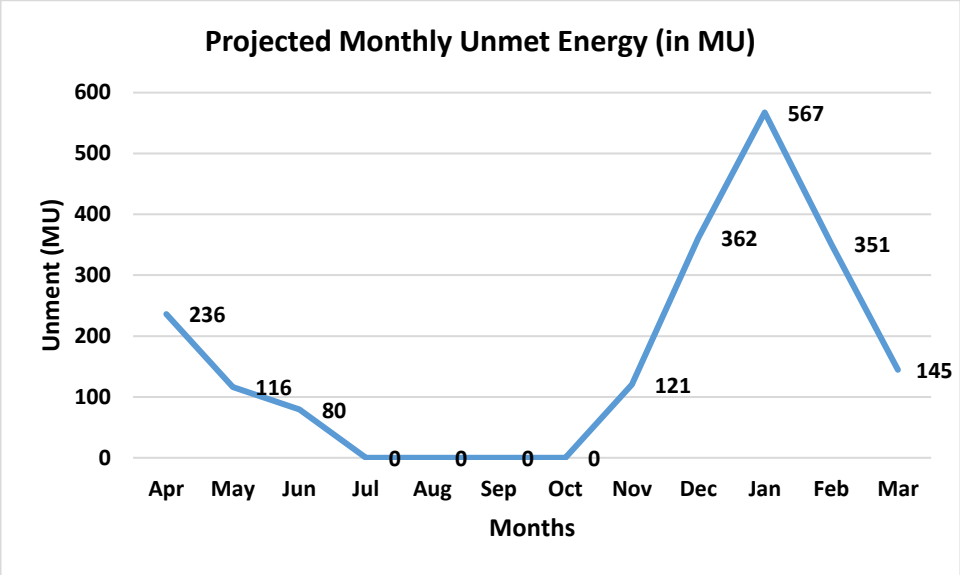

Figure 6 Likely month-wise Unserved Energy (MU) for the year 2029-30

5.2 Capacity Mix Projection

To meet the unserved energy, energy investment options (candidate capacities) are considered in the studies to find the least cost optimal capacity mix required to meet the projected demand. The following is observed:

i) The STOA/MTOA requirement can be fulfilled through power procurement from markets or bilateral agreements.

ii) The STOA/MTOA value reflects the peak value requirement in terms of MW.

The capacity projections for Uttarakhand are given below:

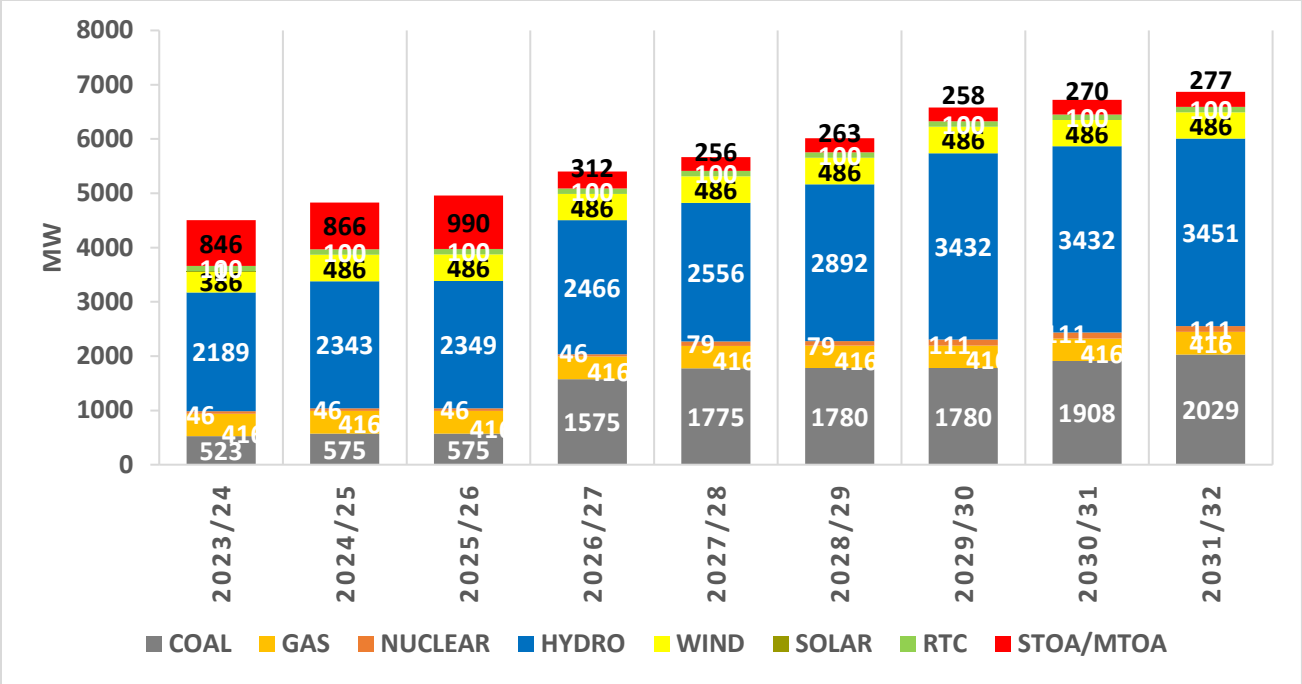

Figure 7 Projected Capacity Mix Year-wise (MW) for Uttarakhand

As per the Resource Adequacy studies, the total projected Capacity for the year 2029-30 is 6577 MW which consists of 1780 MW from Coal, 416 MW from Gas, 111 MW from Nuclear, 3432 MW from Hydro, 486 MW from Solar, 200MW from PSP, 52 MW from Cogeneration plants, 100MW of RTC and additionally 175 MW from STOA. This installed capacity is able to meet the projected demand with prescribed reliability criteria.

The Reliability studies have been carried out to adhere to the reliability criteria of LoLP and NENS as provided in NEP (0.2% and 0.05% respectively). The PRM for the state of Uttarakhand has been assessed as 5%. In addition, the projected/contracted capacity fulfils the stipulated Renewable Purchase Obligation.

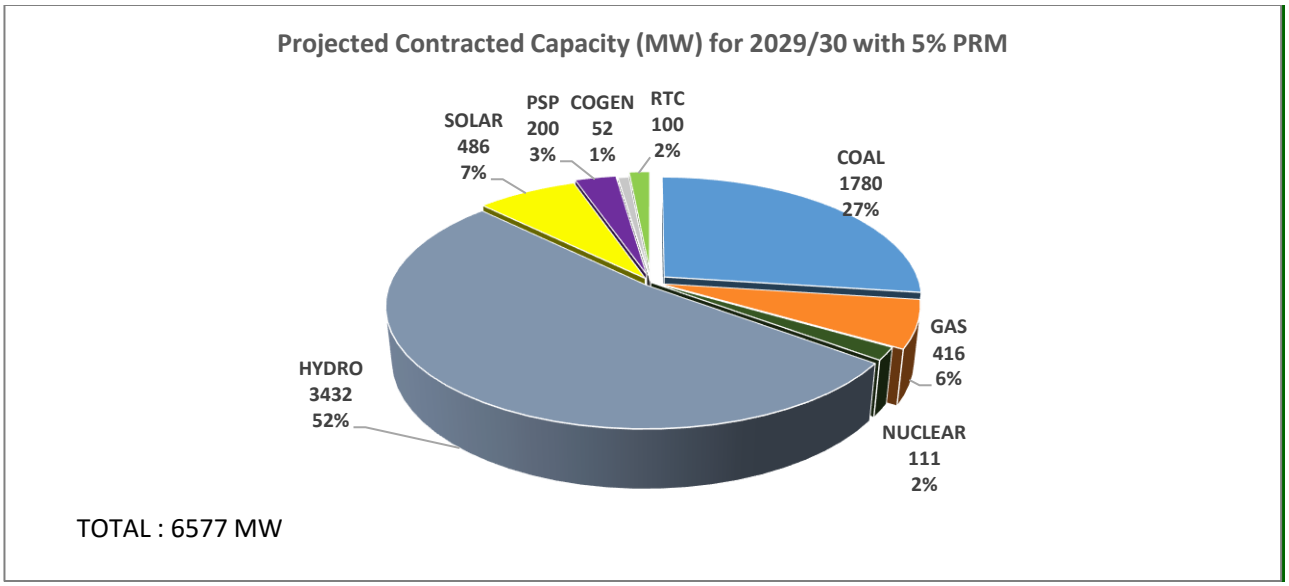

Figure 8 Projected Contracted Capacity Mix in 2029-30 with 22.3 % PRM

The contribution of STOA or dependence on market in the generation mix for meeting the peak demand requirement is seen to be up-to around 5.5% in 2030.

The likely share of different projected capacities in the generation mix of the state upto 2031-32 based on the studies, is shown in the Figure 9 below:

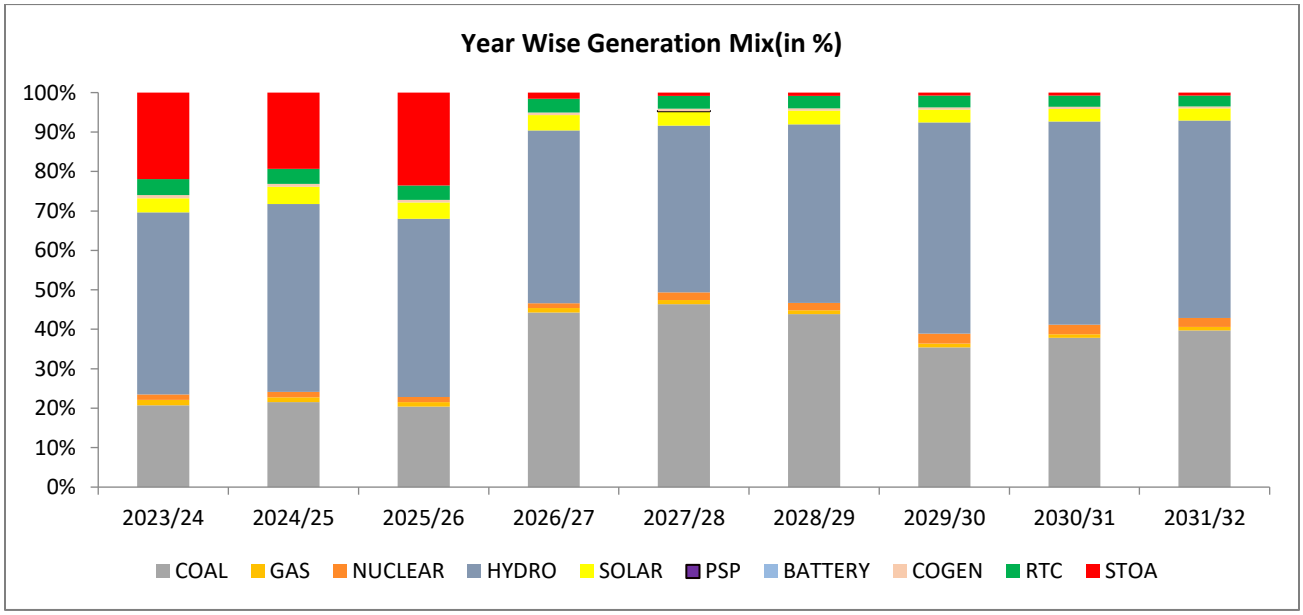

Figure 9 Year-wise projected generation mix (in %)

5.4 Day-wise Surplus Capacity for Uttarakhand (MW)

The pattern of surplus capacities has been observed as below. This capacity can be shared with other states and reduce the fixed cost burden on the utilities resulting in reduction in the cost for consumer. Uttarakhand has likely surplus capacity available during the months from May to November

(tentatively in the range of 80-850 MW varying from month to month from the year 2026-27) which can be shared with other states.

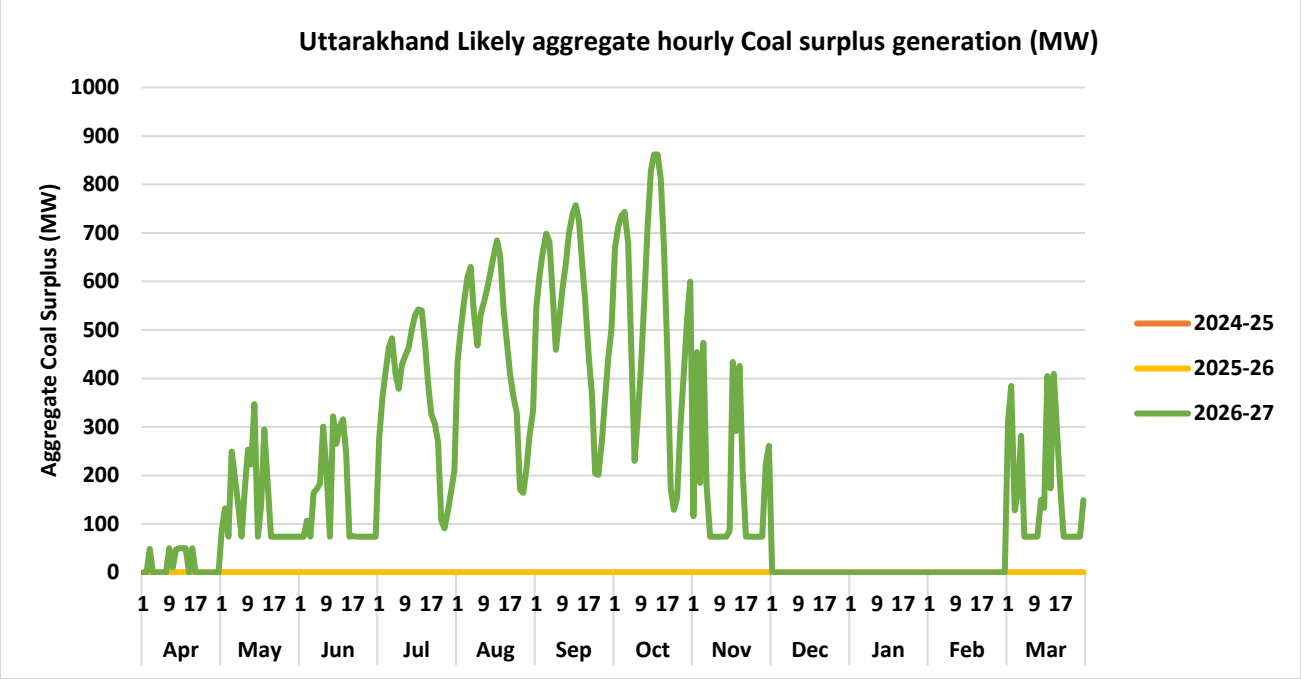

Figure 10 Aggregate Surplus Coal Capacity Year-wise (MW)

5.7 Capacity contract requirement for future

It has been found out in the studies that Uttarakhand needs to contract following capacities (planned and additional) per year till to meet its demand reliably.

Table 7 Year wise Capacity Addition for Uttarakhand (in MW)

Year wise Capacity Addition for Uttarakhand (in MW)									
FY	COAL		Hydro	SOLAR	PSP	RTC	TOTAL		STOA/MTOA
	Planned Contracts	Additional Contracts	Planned Contracts	Planned Contracts	Planned Contracts	Planned Contracts	Planned contract	Additional contract	Additional Contract
2023/24	0	0	27	0	200	100	**327**	**0**	846
2024/25	51.8	0	154	100	0	0	**305.8**	**0**	866
2025/26	0	0	6	0	0	0	**6**	**0**	990
2026/27	0	1000	117	0	0	0	**117**	**1000**	312
2027/28	0	200	90	0	0	0	**90**	**200**	256
2028/29	0	6	336	0	0	0	**336**	**6**	263
2029/30	0	0	539	0	0	0	**539**	**0**	258
2030/31	0	127	0	0	0	0	**0**	**127**	270
2031/32	0	121	20	0	0	0	**20**	**121**	277

6.0 Scenario Analysis-Transition to Green State by 2029-30

A scenario was analyzed for the state wherein the likelihood of Uttarakhand meeting 100% of its power from green sources was studied. In this scenario it was assumed that the power generation of the state from coal and gas based sources is to be replaced by RE sources by 2029-30, thereby the thermal sources are considered to be phased out by 2029-30.

Additionally, its assumed that the market based dependence out of the total likely generation mix in 2029-30 is nearly zero.

6.1 Capacity Mix Projections

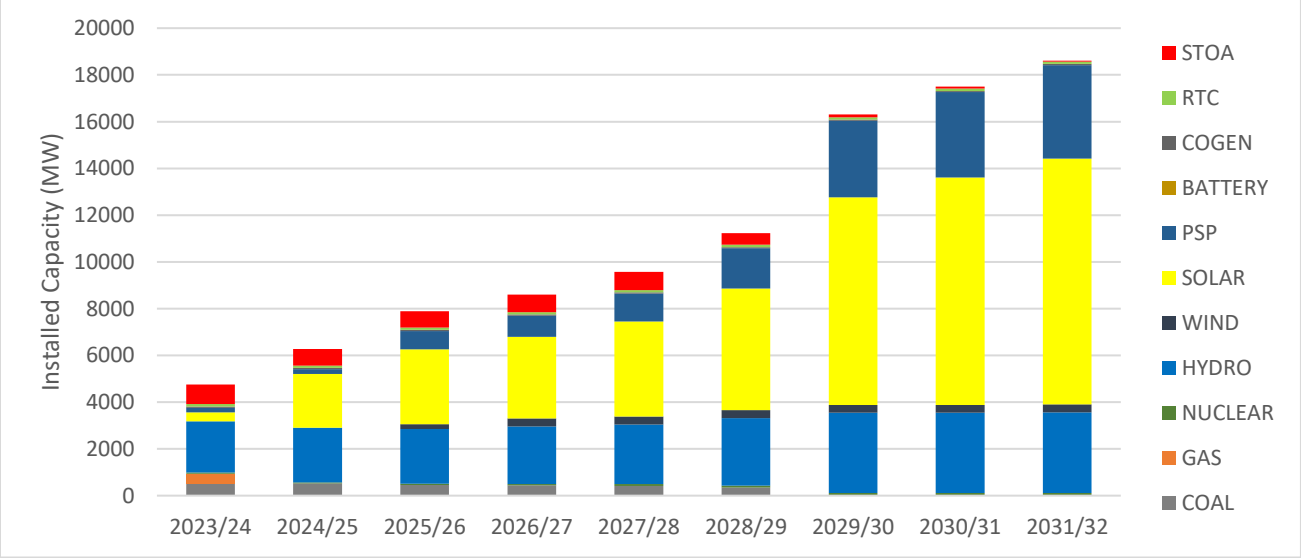

Figure 11: Year-wise capacity projections (in MW) for Green State Scenario

In this scenario, it is seen that the state would require 16186 MW of total capacity comprising of 3432 MW of Hydro, 8884 MW of Solar, 111MW of Nuclear, 340MW of Wind, 52MW of Cogeneration and 100MW of RTC along with 3267 MW of PSP capacity by 2029-30. This implies a capacity addition of 8398 MW of Solar,340MW of Wind and 3067 MW of PSP based capacity up to 2029-30.

7.0 Conclusions

Based on the Resource Adequacy studies for the state of Uttarakhand up to the year 2031-32, the following conclusions may be drawn:

- Existing and future trajectory of Hydro capacity addition indicates that Uttarakhand will be Hydro rich state, fulfilling its RPO obligations without any RE based capacity addition.
- Annual Peak demand for the state occurs in winter months during morning hours. Daily peak observed in early morning/late evening hours.
- Demand of the state peaks during winter months i.e. December to February. It was observed that during these months (from November to March) the Hydro based generation reduces and the state is dependent on coal based generation to meet the demand. However, during the rest of the months of the year, the demand is met through the green energy sources.
- The existing capacity of Uttarakhand consists of 73 % of Non-fossil fuel based sources.
- Considering only the capacity addition planned by the state till 2030, the energy demand of 8.3 % is likely to be unserved during the period of Nov to Jun in the year 2029-30.
- The share of coal based capacity in the total capacity mix of the state is likely to increase from 13% as on 2023-24 to 27 % by 2029-30 and 30% by 2031-32. As per the studies, the state requires coal based capacity addition of 1448 MW in order to meet its increasing demand starting from the year 2026-27.
- As per the projected capacity addition as furnished by the state from Hydro and Solar sources, the state doesn't require any additional RE capacity addition till 2032 in order to meet the RPO obligations.
- The Planning Reserve Margin of the state for the year 2029-30 is estimated to be 5%. With this, the state is likely to meet the envisaged reliability targets of 0.2% LOLP and 0.05% NENS respectively.
- An additional scenario was studied for the state wherein the likelihood of Uttarakhand meeting 100% of its power from green sources was studied. As per the studies, solar capacity addition requirement along with PSP based storage is seen to have increased significantly.

8.0 Assumptions for Resource Adequacy Studies for the state of Uttarakhand

1. Electricity Demand & peak requirement: As per 20th Electric Power Survey
2. Demand Profile: Based on hourly demand profile of 2022-23 (2020-21 & 2021-22 were neglected due to Covid)

3. Existing & Planned Capacity: As per the information received from UPCL
4. Future Capacity addition: based on RPO trajectory
5. Cost parameters: based on information available from UPCL or as per National Electricity Plan.

RE CUF considered

Existing Hydro PLF	Planned Hydro PLF (average)	Bioenergy PLF	Existing Solar CUF	Planned Solar CUF	Existing Wind CUF	Planned Wind CUF	Small Hydro CUF
45%	45%	30%	23%	24%	24%	24%	17%

RPO Trajectory

	RPO Target Trajectory (%)							
	2022-23	**2023-24**	**2024-25**	**2025-26**	**2026-27**	**2027-28**	**2028-29**	**2029-30**
Wind RPO	0.81	1.60	2.46	3.36	4.29	5.23	6.16	6.94
Hydro RPO	0.35	0.66	1.08	1.48	1.80	2.15	2.51	2.82
Other RPO	23.44	24.81	26.37	28.17	29.86	31.43	32.69	33.57

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 in the year 2021-2022:

Resource	Capex* (in ₹/MW)	O&M Fixed Cost (in ₹/MW)	Construction Time (in years)	Amortization /Life time (in years)
Coal	8.34 Cr	19.54 Lakh	4	25
Hydro~	6 Cr to 20 Cr	2.5% of Capex	5 to 8	40
Solar**	4.5 Cr to 4.1 Cr	1 % of Capex	0.5	25
Wind(Onshore)	6 Cr	1% of Capex	1.5	25
Wind(Offshore)	13.7 Cr	1% of Capex	1.5	25
Biomass	9 Cr	2% of Capex	3	20
Pumped Storage	3 Cr to 8 Cr	5 % of Capex	7	40
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

* All the Capex figures are on actual basis at the cost level of 2021-22 i.e., inflation is not considered while calculating capex.

~ The Capex values of Hydro and PSS candidates are considered as per the project cost details furnished by the respective developers for state and private sector plants and as per RCEs done periodically by CEA for central sector plants.

**Solar Cost is assumed to reduce from Rs 4.5 Cr/MW in 2021-22 to Rs 4.1 Cr/MW in 2029-30.