REPORT ON
RESOURCE ADEQUACY PLAN
FOR THE STATE OF
HIMACHAL PRADESH

GOVERNMENT OF INDIA
MINISTRY OF POWER
CENTRAL ELECTRICITY AUTHORITY

Contents

Executive Summary

The electricity demand for the State of Himachal Pradesh is increasing with a CAGR of 4.25 % from 2023-24 to 2029-30 as forecasted by 20th EPS. The projections of HPSEBL also indicate that electricity demand may increase with a CAGR of 4 % 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 November 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 lowest electricity demand month is generally in the month of March. 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 Discoms 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 HPSEBL makes it 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 Himachal Pradesh based on inputs received from HPSEBL. 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 2029-30, long-term study for the State of Himachal Pradesh 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 study was carried out considering existing capacity, planned capacity & capacity required to fulfil the Renewable Purchase Obligations (RPO). It was observed that the total unserved energy in the year 2029-30 is expected to be about 5771.16 MU which is about 3.27% annual energy during the year 2029-30 and primarily observed in the months from November to February. 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. However, based on the discussions with the state officials, an alternative scenario has been studied in view of the demand projections provided by HPSEBL while the RPO trajectory has been adhered as per the notification of MoP.

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 Himachal Pradesh based on the inputs received from HPSEBL and as per RPO trajectory. The study suggests the optimal resource mix till 2030 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 Himachal Pradesh for catering to above highlighted uncertainties so that demand can be met reliably throughout the year.

2.0 Himachal Pradesh RA Study

2.1 Present Power Scenario in Himachal Pradesh

As of August 2022, the total contracted capacity for Himachal Pradesh is 3512 MW. Out of the total contracted capacity (CC), the share of non-fossil fuel-based CC is 95.4 %.
The fuel-wise contracted capacity as on August 2022 is given in Table 1 and Figure 1 below:

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

Source	Contracted Capacity (MW)	Percentage
Coal	160	4.6
Nuclear	29	0.8
Hydro	3248	92.5
Solar	75	2.1
Total	3512	100

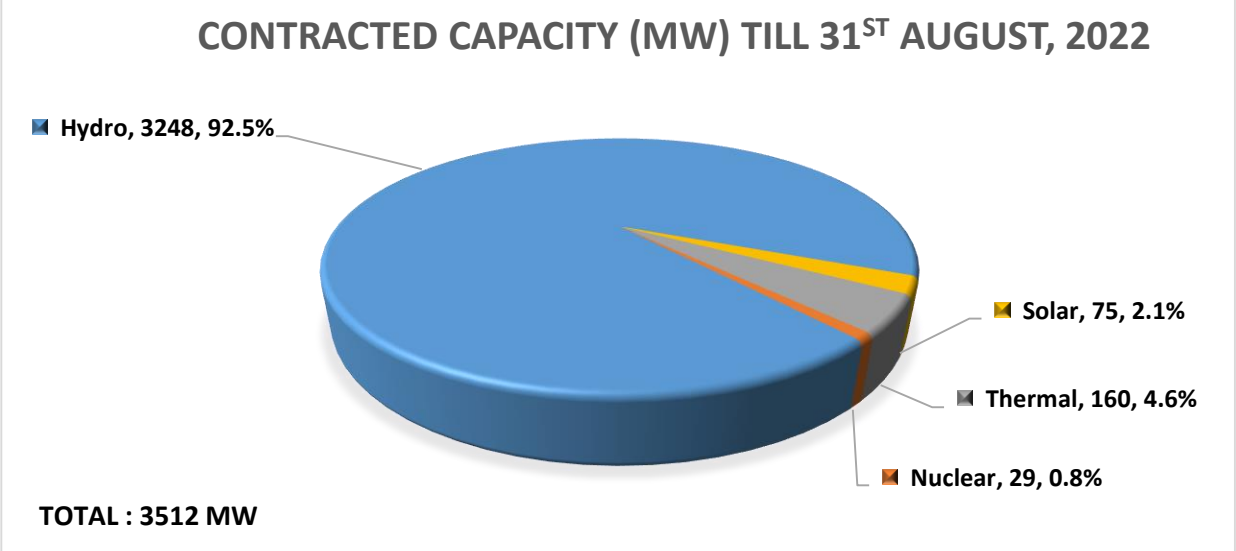

Figure 1 Fuel-wise Contracted Capacity (in MW) as on 31st August, 2022

2.2 Present Demand Analysis (2022-23)

Hourly demand pattern of 2022-23 was analyzed and it was observed that the peak demand for Himachal Pradesh occurs during the winter months viz November, December, January and February. The hourly demand pattern during winter months is significantly different than the rest of the months. Himachal Pradesh witnesses peak demand during day hours in the winter months while there is not much difference in day and night peak demand during the lean demand months. The

Demand during the month of August & September is almost half as observed during the month of Dec, Jan and Feb which reflects the effect of seasonality in demand. 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 Figure 2 given below:

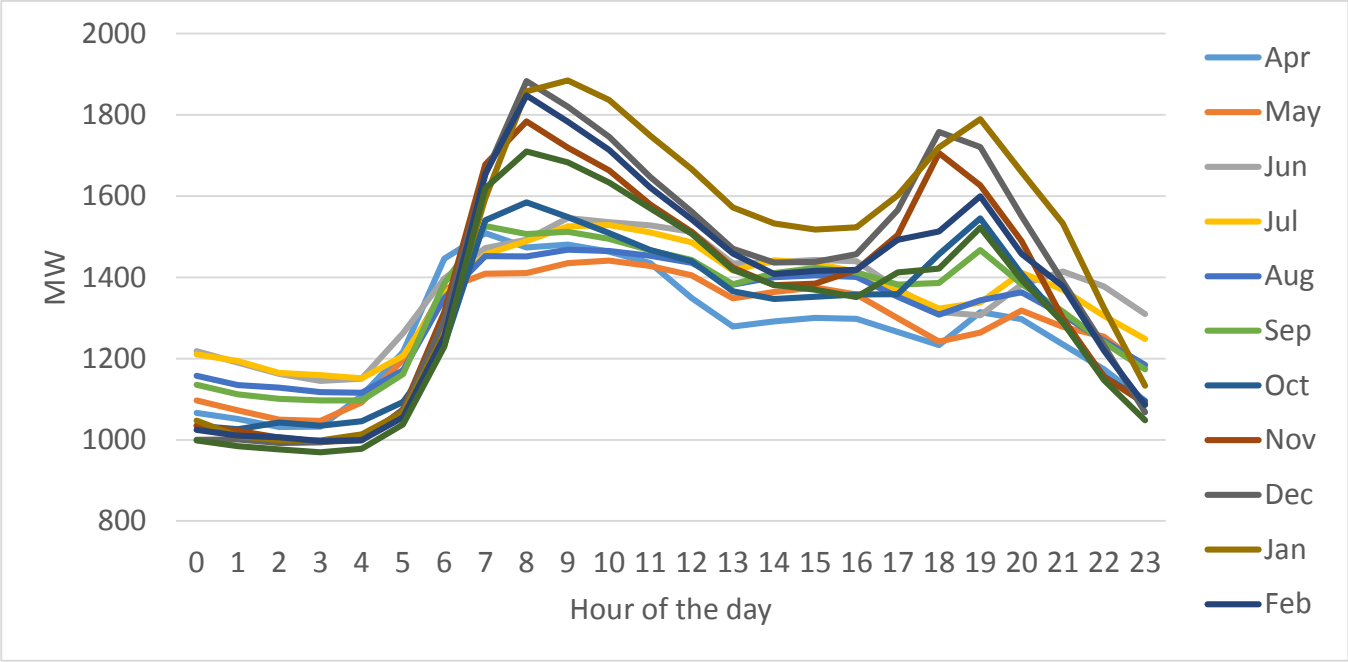

Figure 2 Average Hourly Demand Variation (Month-wise) of Himachal Pradesh for 2022-23

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

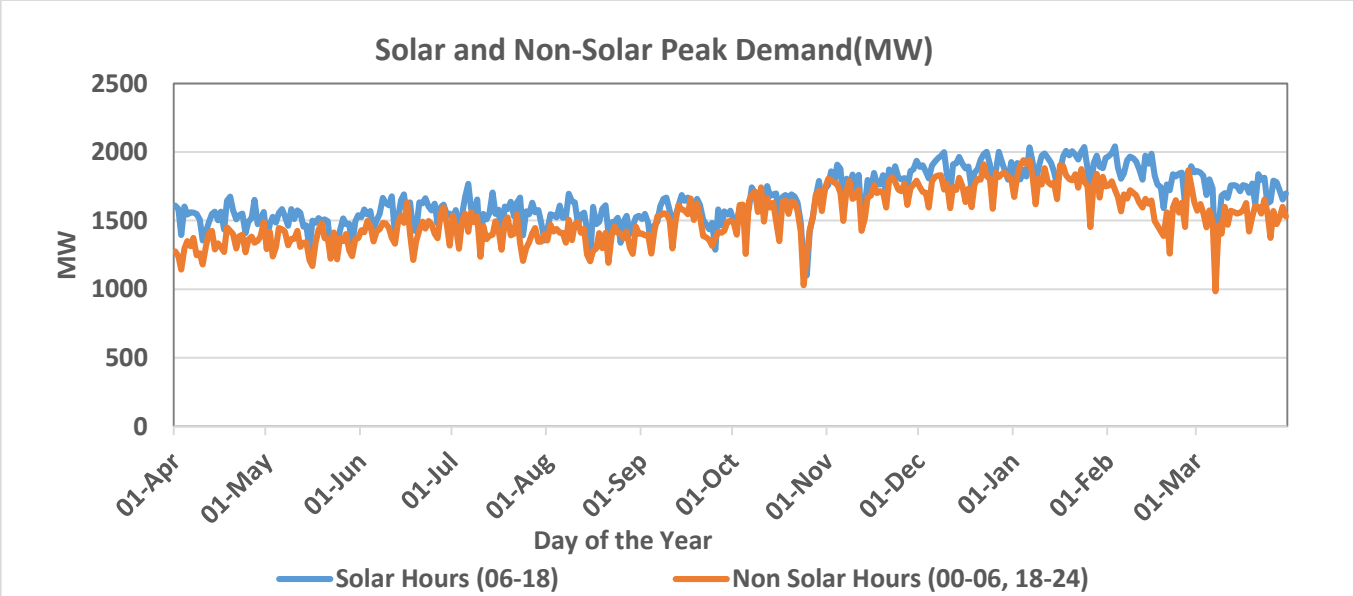

Figure 3 Day and Night Peak in MW of Himachal Pradesh (2022-23)

3.0 Inputs/Assumptions for the Study

i) The Peak and Energy Demand for the state of Himachal Pradesh 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 4, the Demand estimation by HPSEBL 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

	2023-24	**2024-25**	**2025-26**	**2026-27**	**2027-28**	**2028-29**	**2029-30**	**2030-31**	**2031-32**
Energy Projections (MU)	13172 (**8324***)	13829	14522	15238	15979	16730	17628	18222	18807
Year on Year Growth	-	4.99%	5.01%	4.93%	4.86%	4.7%	5.37%	3.37%	3.21%
Peak Demand Projections (MW)	2215 (**1977***)	2328	2448	2571	2699	2829	2983	3087	3190
Year on Year Growth	4.53%	5.10%	5.20%	5.02%	4.98%	4.82%	5.44%	3.49%	3.34%

*Actual energy consumption and peak demand as per Power Supply Position report of CEA(till Sept, 2023).

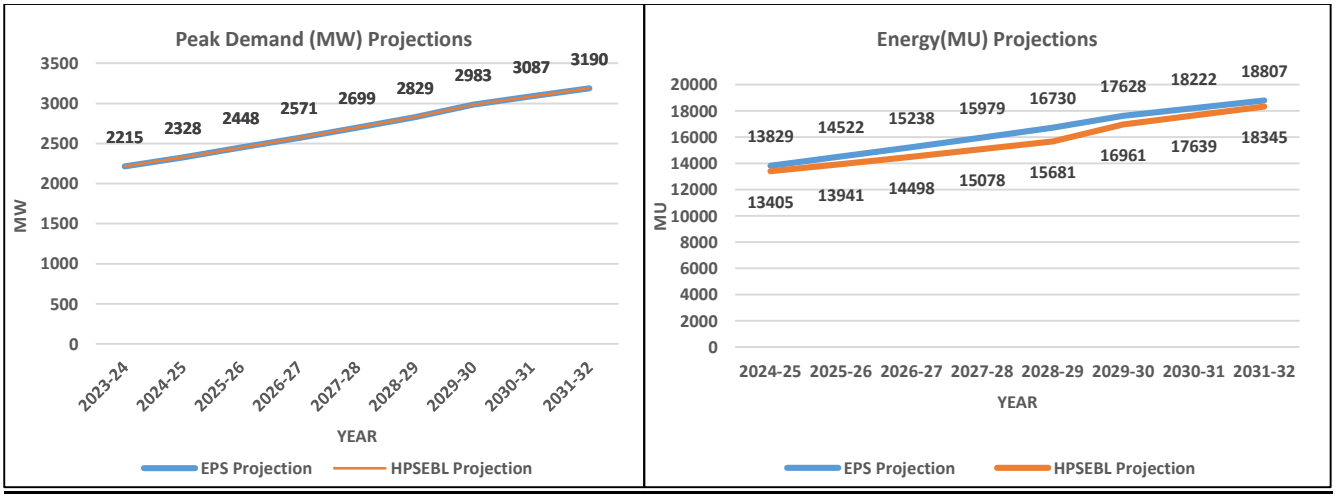

Figure 4 Comparison of Energy Requirement and peak Demand Projections of EPS vs MP

ii) Future demand profile for the year 2029-30 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 has 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 the likely allocation from nuclear project of RAPP from the year 2026-27 onwards (based on the central sector projects allocation guidelines). Additionally, 13 % free power from under construction central sector hydro projects located in the state namely HEP Parbati stage-II (U1-4), Dhaulasidh (U1), Luhri, Sunni Dam have also been considered for benefits during the study period.

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
Thermal	0	0	0	0	0	0	0	0	0	**0**
Solar	100	100	100	150	150	200	200	200	200	**1400**
Wind	0	0	0	0	0	0	0	0	0	**0**
Hydro	298	358	855	199	199	59	108	0	0	**2074**
Biomass	0	0	0	0	0	0	0	0	0	**0**
Nuclear	0	0	0	26	0	0	0	0	0	**26**
Total	**398**	**458**	**955**	**375**	**349**	**259**	**308**	**200**	**200**	**3500**

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, Himachal Pradesh 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	**211**	**340**	**488**	**654**	**836**	**1031**	**1223**
Wind RPO	**87**	**149**	**215**	**274**	**344**	**420**	**497**
Other RPO	**3268**	**3647**	**4091**	**4550**	**5022**	**5469**	**5918**

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	**738**	**1617**	**2266**	**2459**	**2682**	**4425**	**4585**

Wind Generation	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Generation eligible for Other RPO	**10066**	**10089**	**10865**	**10868**	**10872**	**10876**	**10880**

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	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Wind RPO	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Other RPO	**6798**	**6442**	**6774**	**6318**	**5850**	**5407**	**4962**

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

Table 6 As per RPO trajectory, Himachal Pradesh 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 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.

Peak 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:-

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

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. An 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 HPSEBL for last 5 years was analyzed. The hourly demand variation for consecutive years (i.e., 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 form other years because of COVID pandemic. The pattern of % variation in hourly demand for the years 2018-19, 2019-20 and 2022-23 is shown in Figure 5 below.

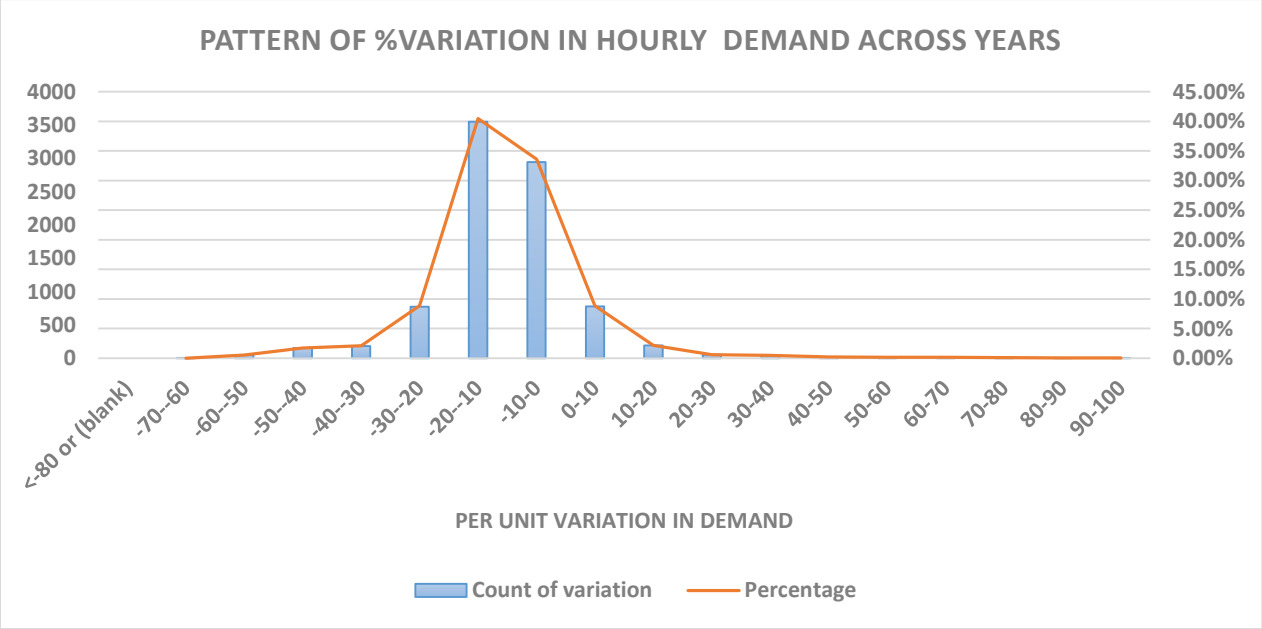

Figure 5 Hourly Variation in Demand across years

It can be observed that the hourly demand typically varies ±20% for 85.13% of instances and ±10% for 42.47% 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 ±20% 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 of HPSEBL 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 577MWh. The likely yearly unserved energy with the planned capacities for the period 2023-24 to 2029-30 is shown in Figure 6 below.

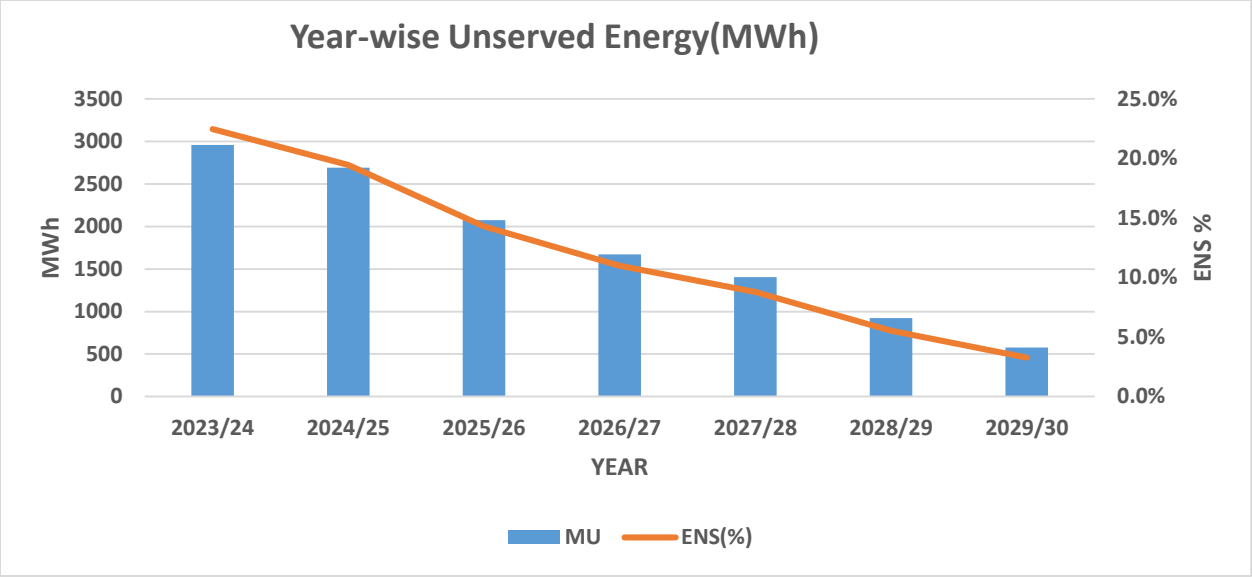

Figure 6 Yearly likely unserved energy with the planned capacities for Himachal Pradesh (in MU)

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.

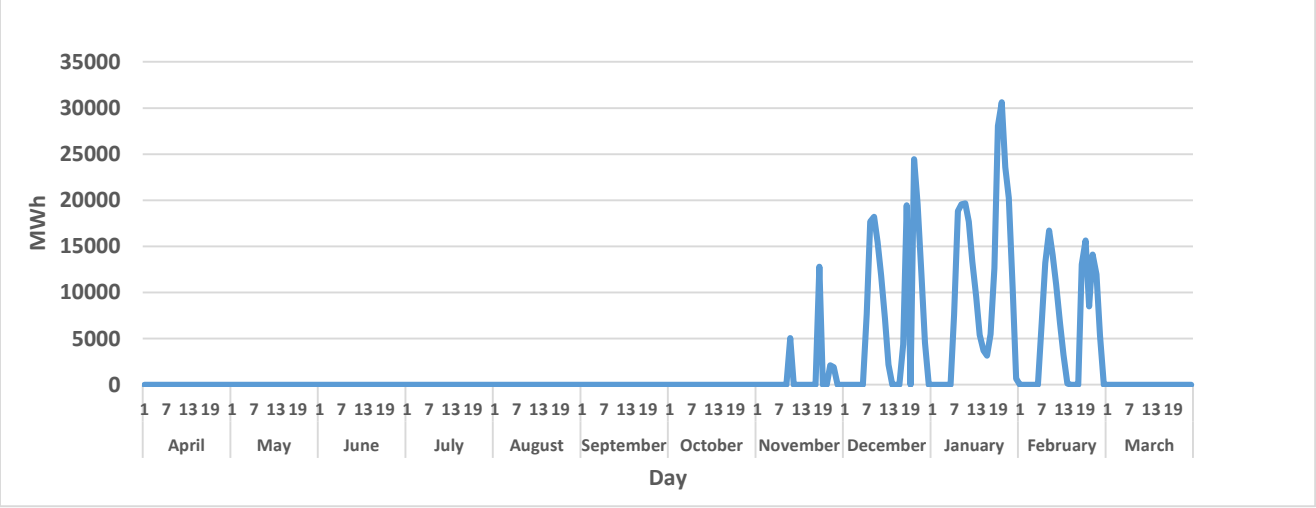

Figure 7 Likely day-wise Unserved Energy (MWh) for the year 2029-30

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 Himachal Pradesh are shown in Figure 8 below:

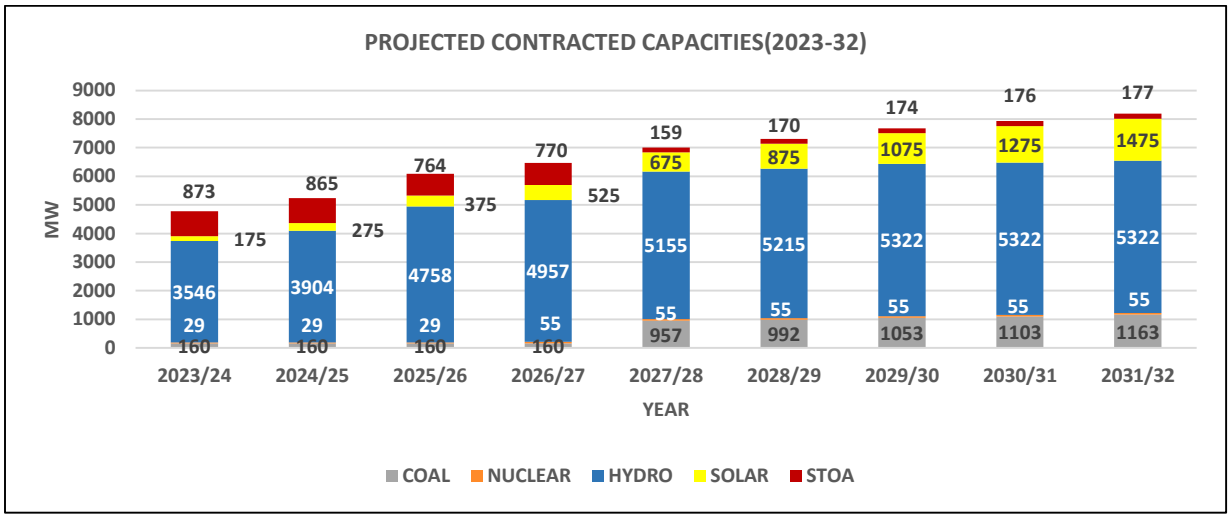

Figure 8 Projected Capacity Mix Year-wise (MW) for Himachal Pradesh

As per the Resource Adequacy studies, the total projected Capacity for the year 2029-30 is 7505 MW which consists of 1053 MW from Coal, 55 MW from Nuclear, 5322 MW from Hydro, 1075 MW from Solar and additionally 175 MW from STOA. This IC 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 Himachal Pradesh has been assessed as 17%. In addition, the projected/contracted capacity fulfils the stipulated Renewable Purchase Obligation.

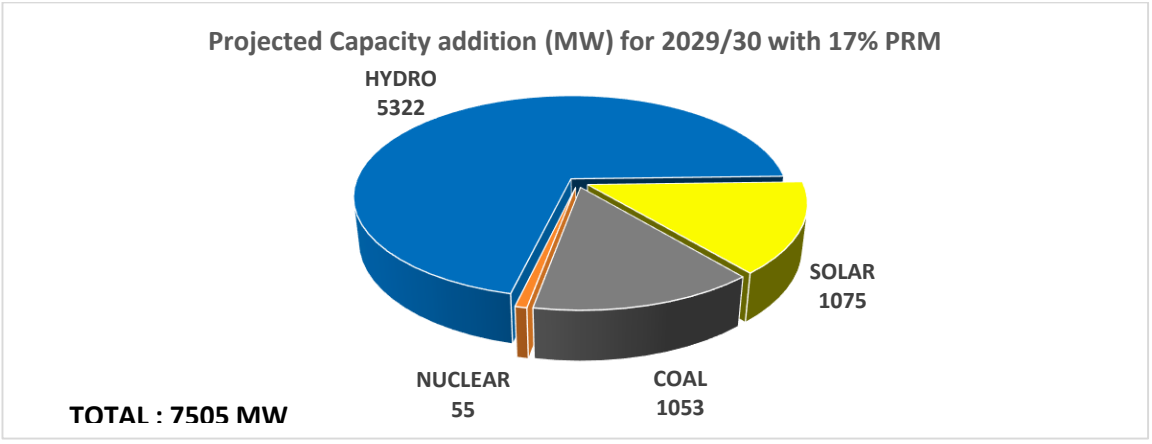

Figure 9 Projected Contracted Capacity Mix in 2029-30 with 17% PRM

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 1% in 2030.

The likely share of different projected capacities in the generation mix of the state upto 2029-30 based on the studies, is shown in the Figure 10 below:

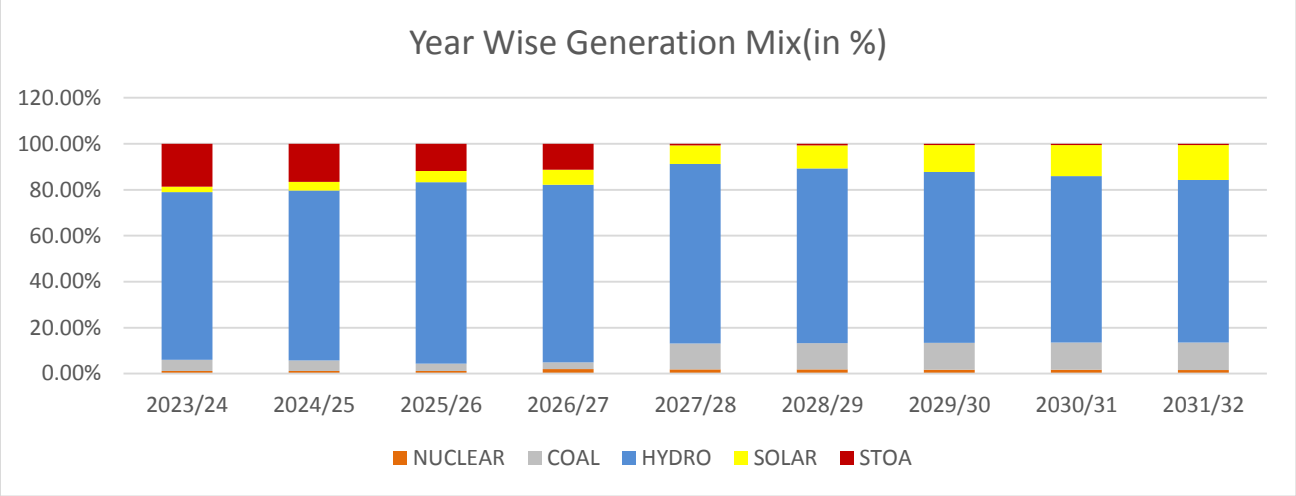

Figure 10 Year-wise projected generation mix (in %)

5.4 Day-wise Surplus Capacity for Himachal Pradesh (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. Himachal Pradesh has likely surplus capacity available during the months from May to September (tentatively in the range of 600-800 MW from 2027-28) which can be shared with other states.

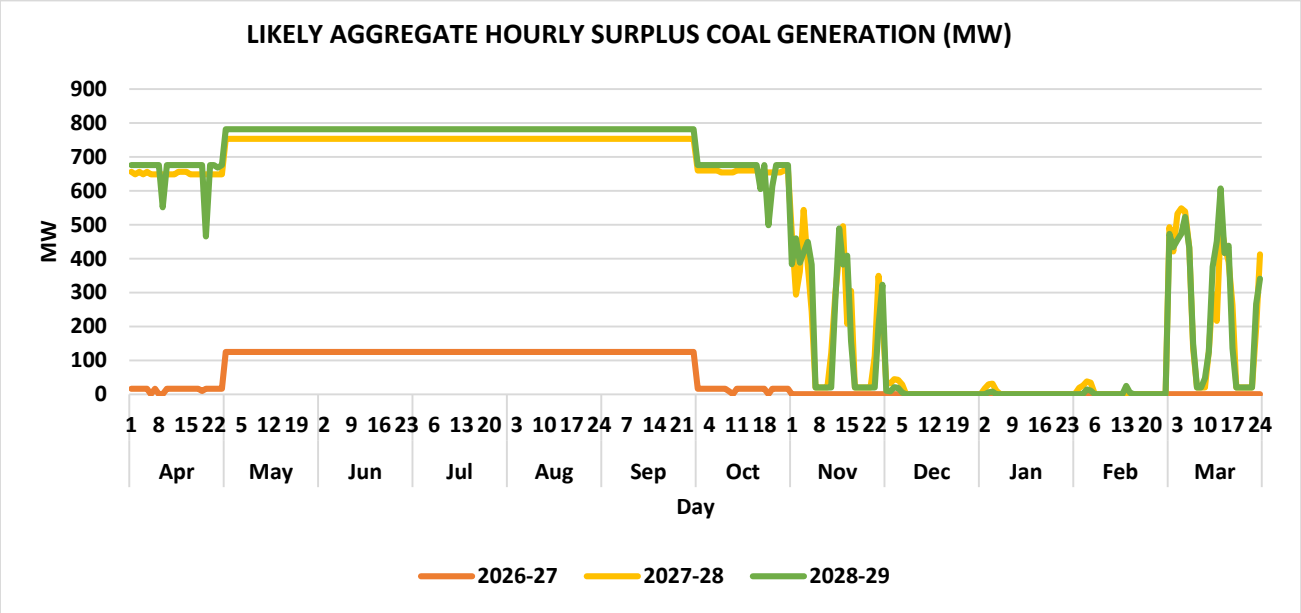

Figure 11 Surplus Coal Capacity Year-wise (MW)

5.7 Capacity contract requirement for future

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

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

FY	COAL		HYDRO		NUCLEAR		SOLAR		TOTAL		STOA/ MTOA
	Planned contract	Additional contract	Planned contract	Additional contract	Planned contract	Additional contract	Planned contract	Additional contract	Planned contract	Additional contract	
2023/24	0	0	298	0	0	0	100	0	398	0	873
2024/25	0	0	358	0	0	0	100	0	458	0	865
2025/26	0	0	855	0	0	0	100	0	955	0	764
2026/27	0	0	199	0	26	0	150	0	375	0	770
2027/28	0	797	199	0	0	0	150	0	349	797	159
2028/29	0	35	59	0	0	0	200	0	259	35	170
2029/30	0	61	108	0	0	0	200	0	308	61	174
2030/31	0	49	0	0	0	0	200	0	200	49	176
2031/32	0	60	0	0	0	0	200	0	200	60	177

- The Projected Contracted Capacities includes the allocation from Central Sector Nuclear Projects namely RAPP (2026-27)
- Based on the central sector projects allocation guidelines, 13 % free power from under construction hydro projects namely HEP PARBATI ST. II UNIT 1-4, HEP Dhaulasidh U1, HEP Luhri, HEP Sunni Dam has also been considered during the study period

6.0 Alternate Resilient Scenario Analysis

In view of the recent surge in Power demand during the year 2023-24 and capacity addition being delayed compared to the envisaged timelines, it was realized that a stress scenario may be assessed to comprehend such situations arising in the future and prepare the utilities for navigating such challenging situations optimally so as to fulfil their consumer end demand reliably.

The following cases were considered to occur simultaneously in the Alternate Resilient scenario:

- Peak and Energy Demand- 5% increase compared to the 20th EPS projections
- Capacity Addition being delayed from their anticipated year as follows:

Table 8 Time Delay in commissioning of contracted capacity

Contracted Capacity Type	Years Delayed
Hydro	2
Nuclear	2
Renewable Energy Capacity	1
Coal	1

6.1 Capacity Mix Projections

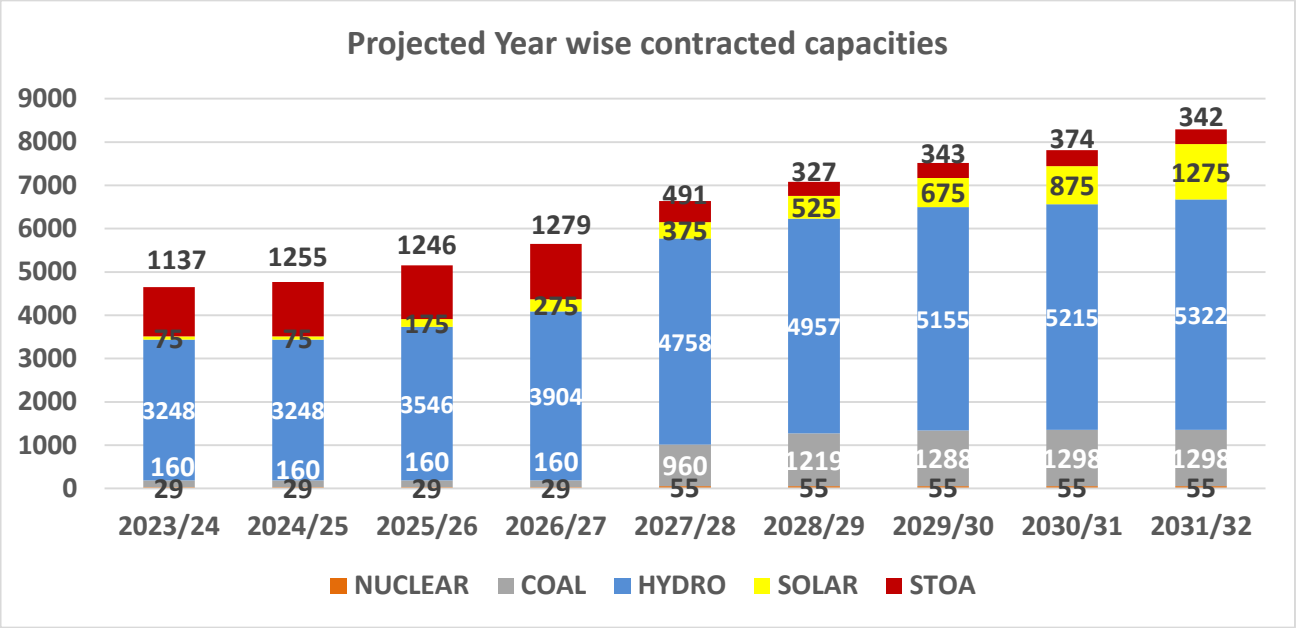

Figure 12 Year-wise capacity projections (in MW) for Most Resilient Scenario

In this scenario, STOA/MTOA requirement is seen to have increased significantly. The coal requirement has also increased from the year 2028/29 onwards compared to the base case.

7.0 Conclusions

Based on the Resource Adequacy studies for the state of Himachal Pradesh up to the year 2029-30, the following conclusions may be drawn:

- Annual Peak demand for the state occurs in winter months during morning hours (10-11 AM). 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 Himachal Pradesh consists of 95.4% of Non-fossil fuel based sources.
- Considering only the capacity addition planned by the state till 2030, the energy demand of 3.27% is likely to be unserved during the period of Nov to Feb in the year2029-30.
- The share of coal based capacity in the total capacity mix of the state is likely to increase from 4% as on 2023-24 to 14.5 % by 2031-32. As per the studies, the state requires coal based capacity addition of 797 MW in order to meet its increasing demand starting from the year 2027-28.

- 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 17%. With this, the state is likely to meet the envisaged reliability targets of 0.2% LOLP and 0.05% NENS respectively.
- An additional alternate resilient scenario was studied to comprehend such situations as unexpected increase in demand and delay in realization of projected capacities. As per the studies, in this scenario the Y-o-Y STOA/MTOA requirement is seen to have increased significantly. The coal requirement also increases from the year 2028/29 onwards compared to the base case (1128 MW additional coal capacity needed in 2029-30 when compared to 893 MW in base case).

8.0 Assumptions for Resource Adequacy Studies for the state of Himachal Pradesh

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 affected)
3. Existing & Planned Capacity: As per the information received from state
4. Future Capacity addition: based on RPO trajectory
5. Cost parameters: based on information received from state

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

Type	Start -up time (hr)

Technology		Availability (%)	Ramping (%/min)	Min. Technical. (%)	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
	Existing/ Planned	2777	2777	10	6	4	-	-	-

Nuclear	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	-	-	-	-	-
	Candidate	-	-	80 %	-	-	-	-	-
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.