



**Report on
Resource Adequacy Plan
(Generation)
for
Punjab
(2025-26 to 2035-36)**

July, 2025

**Government of India
Ministry of Power
Central Electricity Authority**

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Disclaimer

This Resource Adequacy study for the state of Punjab has been conducted based on data and inputs provided by Punjab State Power Corporation Limited (PSPCL). The findings, analysis and conclusions presented in this report are contingent upon the accuracy, completeness and timeliness of the information furnished by PSPCL. Any discrepancies or limitations in the data may affect the outcomes of the study accordingly.

In accordance with the Resource Adequacy Guidelines dated 28th June 2023, each Distribution Licensee is mandated to prepare a Resource Adequacy Plan (RAP) for a 10-year horizon, referred to as the Long-Term Distribution Licensee Resource Adequacy Plan (LT-DRAP), which shall be vetted and validated by the Central Electricity Authority (CEA). CEA has facilitated this study and prepared the report solely to assist PSPCL in fulfilling this requirement.

It is expressly stated that the responsibility for the implementation of the study's recommendations, ensuring the adequacy of electricity resources, and undertaking any related actions rests entirely with PSPCL.

Executive Summary

Ministry of Power had notified the Electricity (Amendment) Rules in December 2022. As per Rule 16 of the Electricity (Amendment) Rules, Ministry of Power has notified Resource Adequacy (RA) Guidelines. According to these Guidelines, 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 electricity demand and electrical energy requirement. This plan shall be vetted/validated by 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.

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 2029-30, 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 electrical energy requirement and peak electricity demand for Punjab is increasing with a CAGR of 4.5% and 4.7% respectively from 2025-26 to 2035-36 as forecasted by PSPCL. 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 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 has been carried out for Punjab considering the existing contract capacity and planned capacity addition. It was found that the state's 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 26.7 BU which is about 21% of the annual projected electrical 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 has been carried with the 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 Punjab 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 42,263 MW which consists of 12043 MW from coal, 137 MW from gas, 197 MW from nuclear, 234 MW from biomass, 3684 MW from hydro, 4950 MW from wind, 16807 MW from solar, 3211 MW from Distributed Renewable Energy (DRE) sources, 2812 MW/ 13082 MWh from Storage. Further, in addition to this, 8000 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 Punjab based on inputs furnished by PSPCL. 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 2029-30, based on inputs from PSPCL 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 2029-30)

1. In the earlier Resource Adequacy (RA) study, the financial year 2022-23 had been considered as the base year, and the study covered the period from 2023-24 to 2029-30. The fuel-wise contracted capacity by PSPCL as on 31st March, 2023 is given in Fig 1.

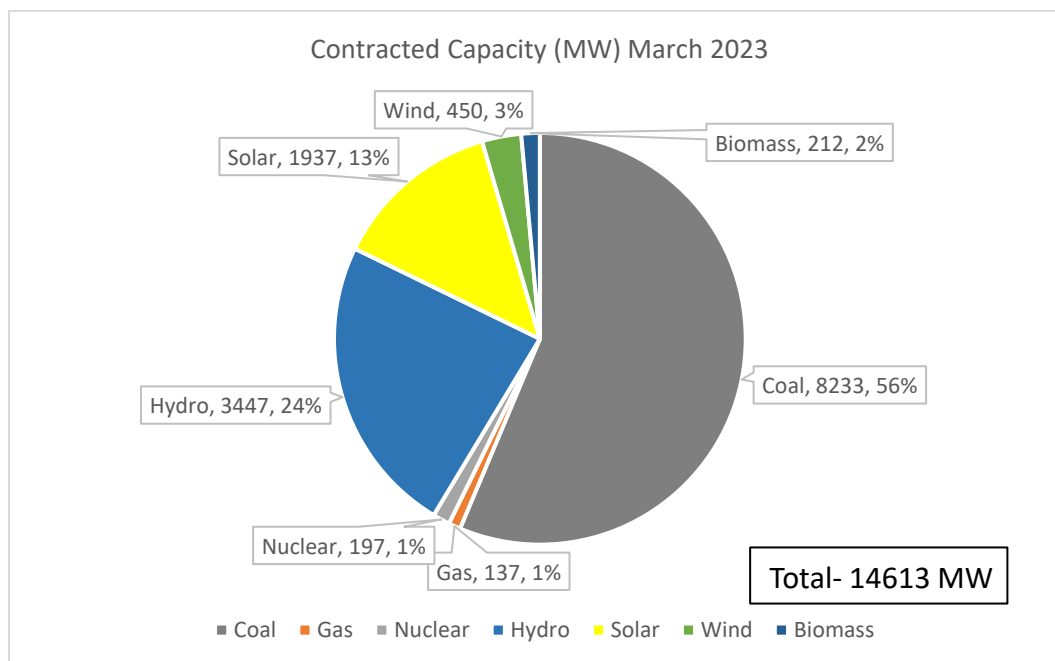


Figure 1: Contract Capacity 2022-23

2. The hourly demand pattern for 2019-20 was analysed and had been considered as a base profile to interpolate the demand for future years.
3. The peak electricity demand and electrical energy projections that was considered in the study is given below:

Table 1: Peak demand and Energy Projections

	2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30
Energy Projections (MU)	69686	73493	77571	81959	86536	91359	97237
Year on Year Growth (%)		5.46%	5.55%	5.66%	5.58%	5.57%	6.43%
Peak Demand Projections (MW)	14859	15502	16189	16925	17684	18478	19466
Year on Year Growth (%)		4.33%	4.43%	4.55%	4.48%	4.49%	5.35%

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

Table 2: Actual Peak Demand and Energy requirement

Year	Actual Energy Requirement (in MU)	Actual Peak Demand (in MW)
2023-24	69,533	15293
2024-25	77,423	16058

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:

Table 3: Projected capacity

YEAR	COAL	GAS	NUCLEAR	HYDRO	WIND	SOLAR	BIOMASS	STOA/ MTOA
2023/24	8233	137	197	3591	953	2988	212	4882
2024/25	8233	137	197	3879	997	4182	212	5180
2025/26	8233	137	197	3879	1538	5593	212	5564
2026/27	11197	137	197	3890	2102	7089	212	5300
2027/28	11197	137	197	4009	2576	8644	212	5300
2028/29	12797	137	197	4142	3094	10167	212	5300
2029/30	13597	137	197	4281	3620	11752	212	5300

*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.

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

Table 4: Year wise planned and additional capacity addition

	Coal		Hydro		Wind	Solar	Total		MTOA/ STOA
Year	Planned contract	Additional contract	Planned contract	Additional contract	Additional contract	Additional contract	Planned contract	Additional contract	Additional Contract
2023/24	0	0	144	0	503	1051	144	1554	4882
2024/25	0	0	288	0	44	1194	288	1238	5180
2025/26	0	0	0	0	541	1411	0	1952	5564
2026/27	0	2964	0	11	564	1496	0	5035	5300
2027/28	800	0	0	119	474	1555	800	2148	5300
2028/29	800	0	0	133	518	1523	800	2174	5300
2029/30	800	0	0	139	526	1586	800	2251	5300
TOTAL	2400	2964	432	402	3170	9816	2832	16352	

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

3.1 Present Power Scenario in Punjab

The current power supply position for Punjab is shown in the Table 5 below.

Table 5: Power Supply Position of Punjab

Power Supply Position						
Year	Energy required (MU)	Energy supplied (MU)	Gap (MU)	Peak Demand (MW)	Peak Met (MW)	Demand not met (MW)
2021-22	62846	62411	436	13556	13541	15
2022-23	69522	69220	302	14311	14311	0
2023-24	69533	69528	5	15293	15293	0
2024-25	77423	77423	0	16058	16058	0

As of March 2025, the total contracted capacity for Punjab is 14,860 MW. Out of the total contracted capacity (CC), the share of non-fossil fuel-based Contracted Capacity is 43.6%.

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

Table 6: Fuel-wise Contracted Capacity as on March 2025

Source	Contracted Capacity (MW)	Percentage (%)
Coal	8232	55.4%
Gas	137	0.9%
Nuclear	197	1.3%
Biomass	235	1.6%
Hydro	3449	23.2%
Wind	450	3.0%
Solar	1705	11.4%
DRE	454	3.0%
Total	14860	100.00%

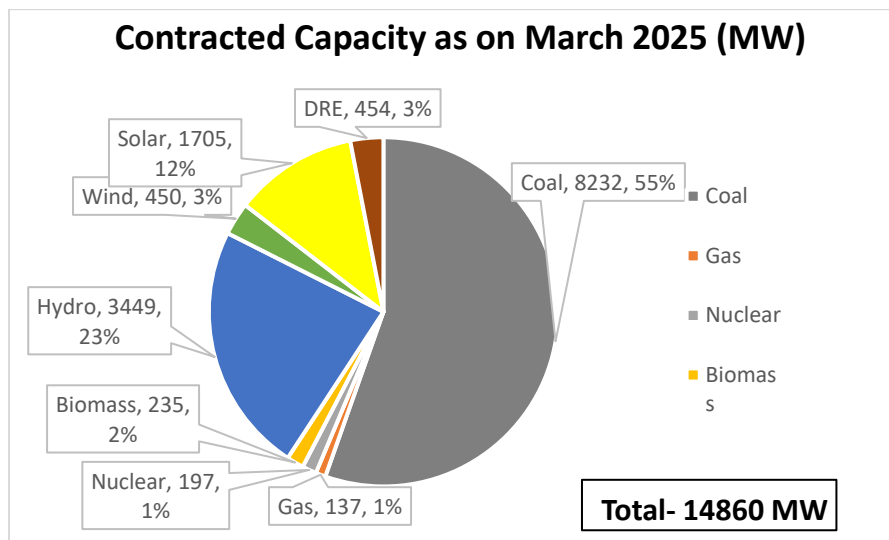


Figure 2 Fuel-wise Contracted Capacity (in MW) as on 31st March, 2025

3.2 Demand Analysis of the FY 2024-25

Hourly demand pattern of 2024-25 was analyzed and it was observed that peak electricity demand in Punjab occurs during the monsoon months, specifically in June, July and August. Notably, the state experiences peak electricity demand during the solar hours in July. Overall, the demand during the solar hours in these months is significantly higher than in the rest of the year.

The month wise variation in average hourly electricity demand observed for the year 2024-25 is shown in Figure 3.

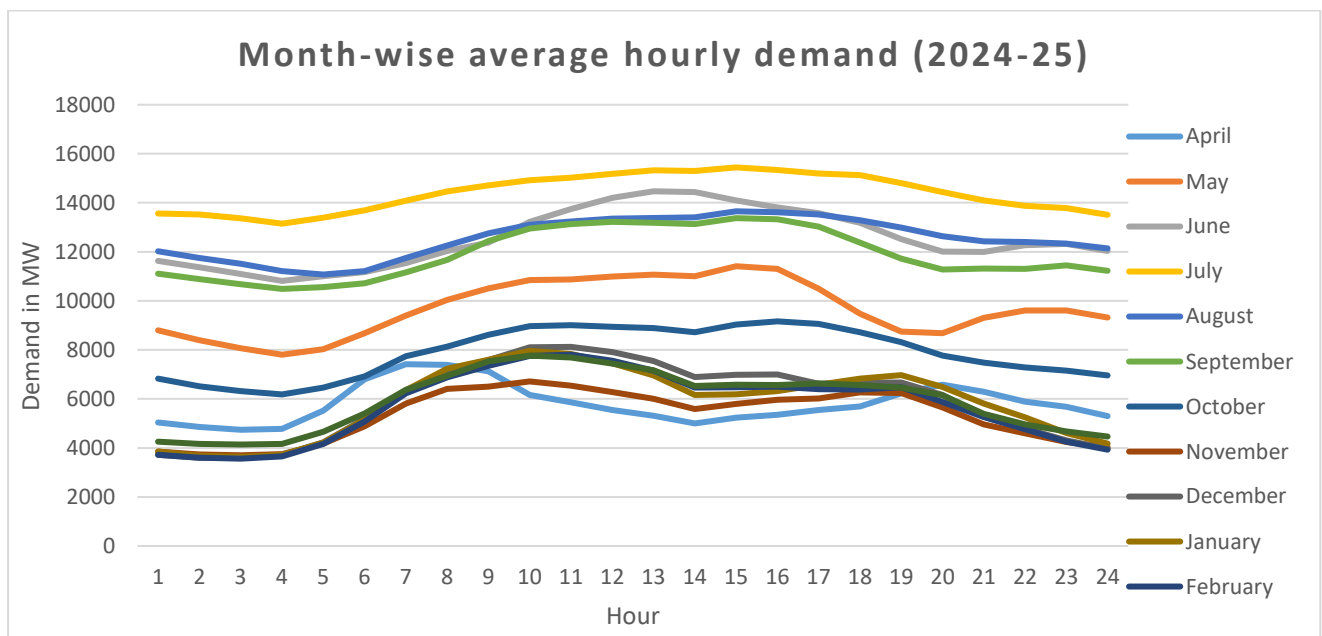


Figure 3: Average Hourly Demand Variation (Month-wise) for 2024-25

From the hourly demand data of 2024-25 the daily peak during solar hours (06:00 to 18:00 hrs) and non-solar hours are plotted in Figure 4.

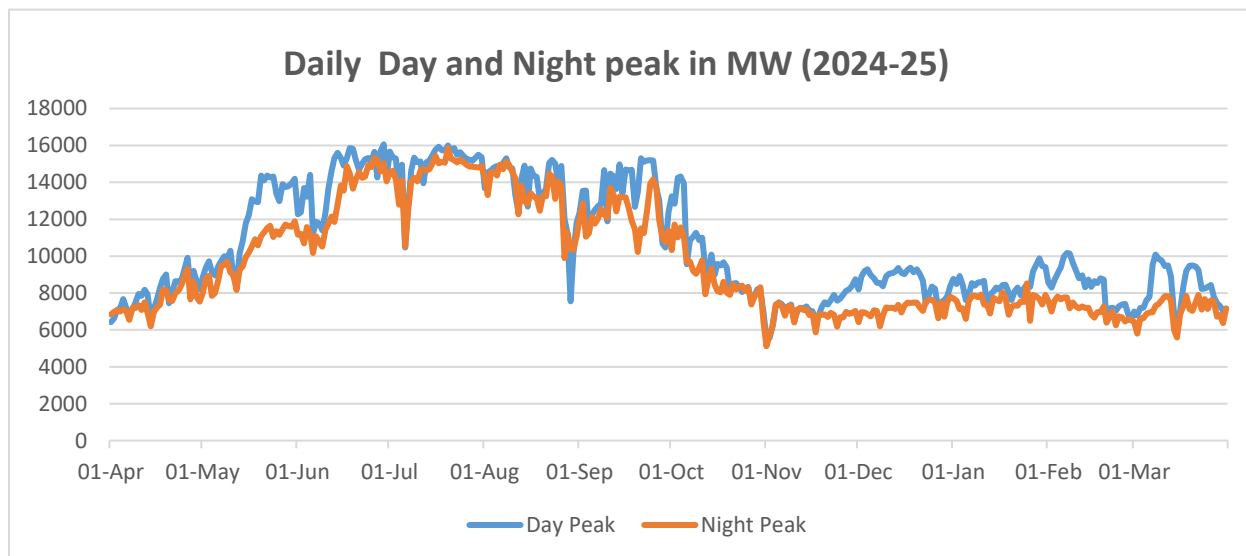


Figure 4: Day and Night Peak in MW for the year 2024-25

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 June to September.

The hourly demand pattern of 2024-25 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.

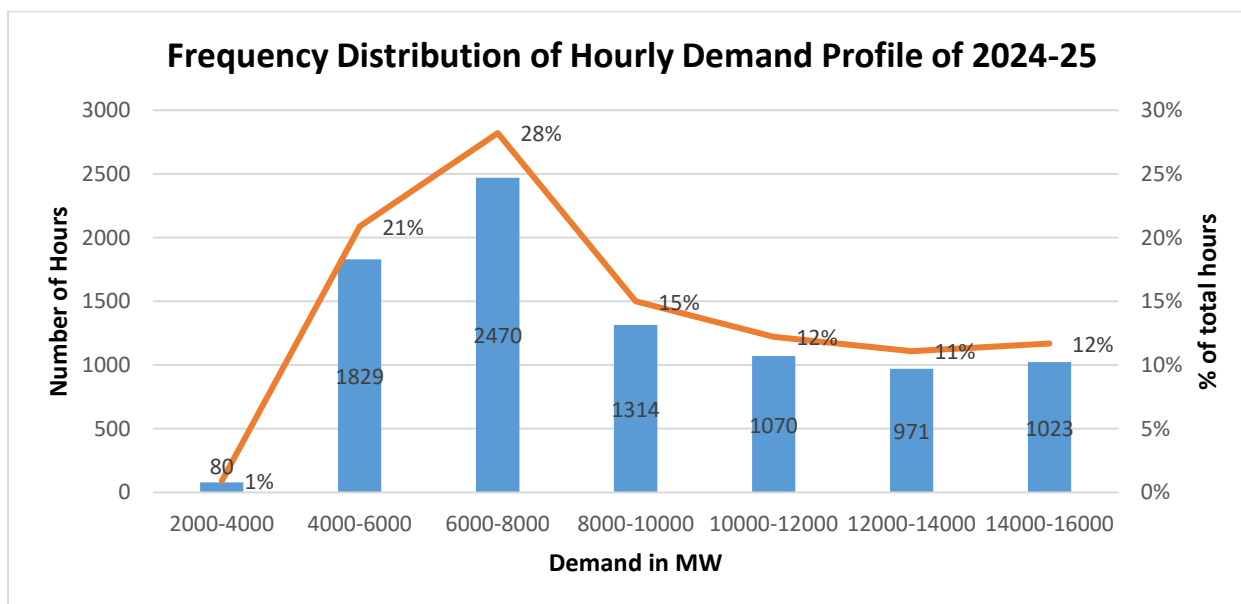


Figure 5 Frequency Distribution of Hourly Demand Profile of 2024-25

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. 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:

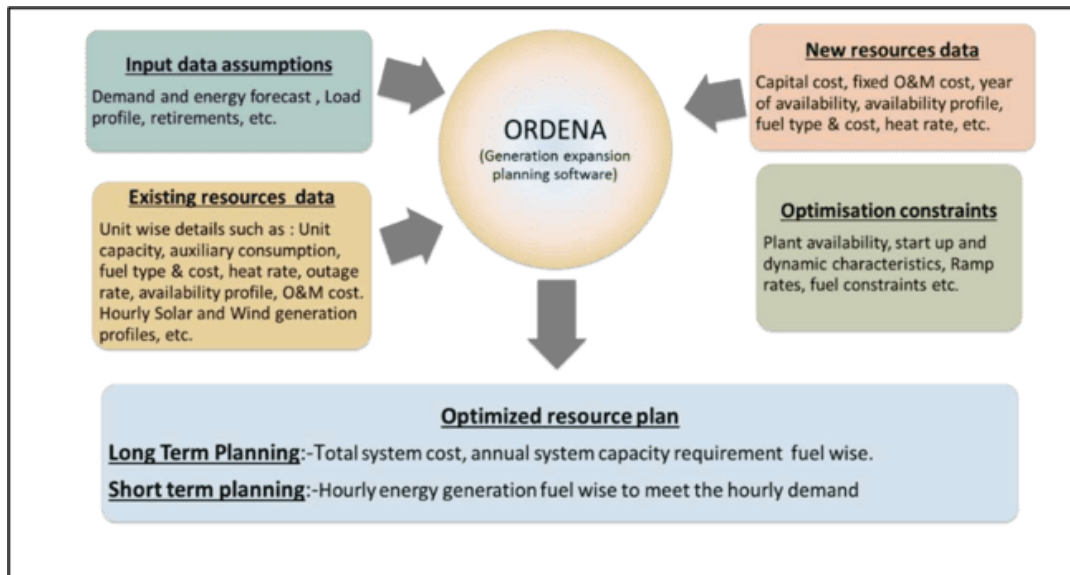
- i) To Supply 24x7 reliable power to consumers
- ii) To achieve objectives of all policies of the Government of India such as RPO trajectory, RE capacity addition
- iii) To achieve sustainable development.
- iv) To fulfil desired operational characteristics of the system such as reliability and flexibility.
- 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 the past two years has been analyzed. The hourly demand variation for consecutive years (i.e., 2023-24 and 2024-25) has been analyzed. The Demand pattern variation of 2023-24 and 2024-25 is shown below.

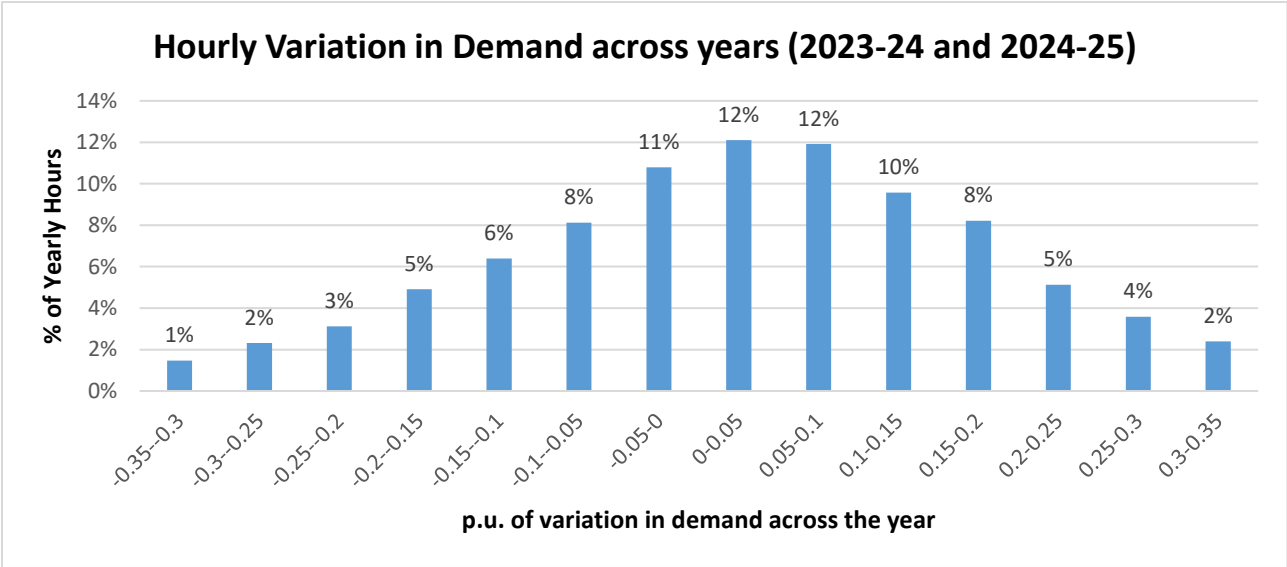


Figure 6 Hourly Variation in Demand across years

It can be observed that the hourly demand typically varies $\pm 15\%$ for 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 $\pm 15\%$ 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 $\pm 10\%$ and wind generation has been varied by $\pm 50\%$ 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 10% with $\pm 5\%$ 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 Punjab, furnished by PSPCL and projections available in the 20th EPS (Electric Power Survey) Mid-term review is tabulated below. The utility's electrical energy requirement and peak electricity demand projections is found to be on the higher side.

Table 7 Future Demand Projection as provided by PSPCL 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)												
PSPCL Peak Demand Projections (in MW)	16058	16941	17873	18767	19705	20690	21570	22486	23442	24438	25477	26560
Year on Year Growth		5.50%	5.50%	5.00%	5.00%	5.00%	4.25%	4.25%	4.25%	4.25%	4.25%	4.25%
20 th EPS Mid-term review Peak Demand Projections (MW)	16129	16897	17668	18207	18791	19351	19860	20350	20858	21348	21834	22455
Year on Year Growth		4.76%	4.57%	3.05%	3.20%	2.98%	2.63%	2.47%	2.50%	2.35%	2.28%	2.84%
Energy Requirement (in MU)												
PSPCL Energy Projections (in MU)	76617	81186	86228	90838	95726	100909	104561	108352	112287	116372	120613	125003
Year on Year Growth		5.96%	6.21%	5.35%	5.38%	5.41%	3.62%	3.63%	3.63%	3.64%	3.64%	3.64%
20 th EPS Mid-term review Energy Projections (in MU)	72342	75768	79213	82827	86715	90574	94257	97924	101739	105530	109366	112475
Year on Year Growth		4.74%	4.55%	4.56%	4.70%	4.45%	4.07%	3.89%	3.90%	3.73%	3.64%	2.84%

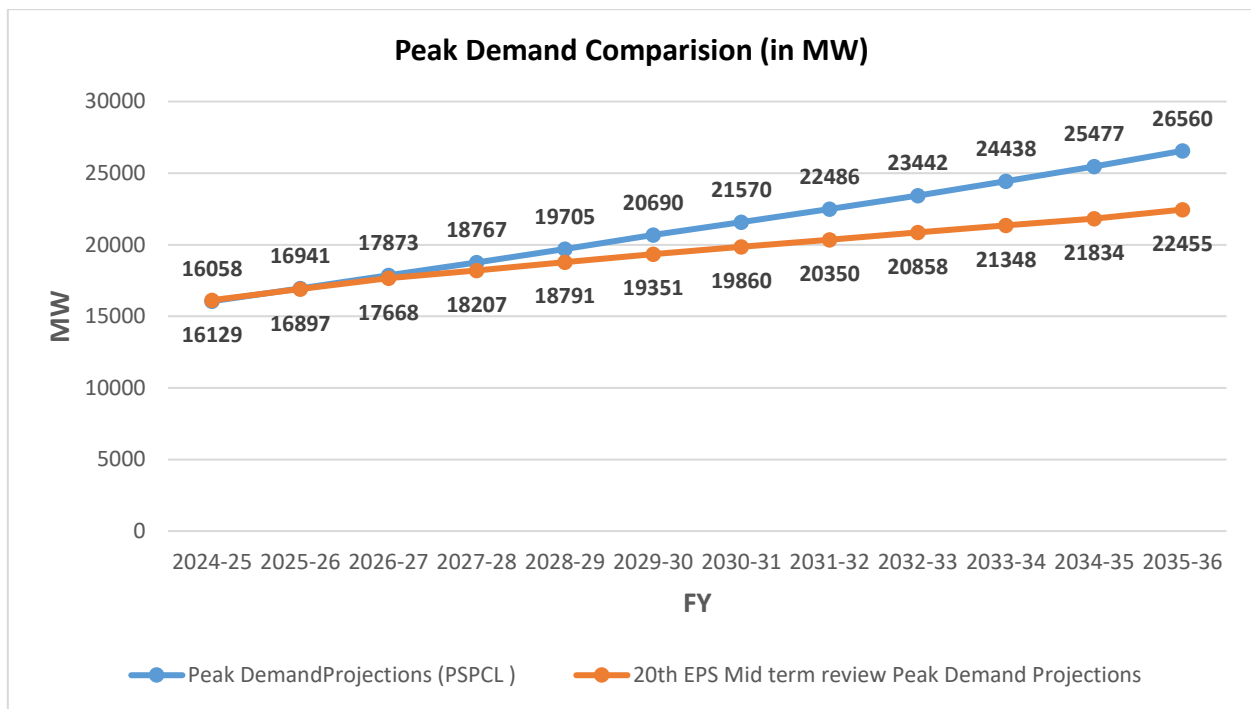


Figure 7 Comparison of Peak Demand Projections of 20th EPS mid-term vs PSPCL

The actual peak load for 2024-25, as per the Peak Power Supply Position (Apr 2024 to Mar 2025) report, stands at 16,058 MW, which is slightly lower than the 20th EPS mid-term review peak load estimate of 16,129 MW.

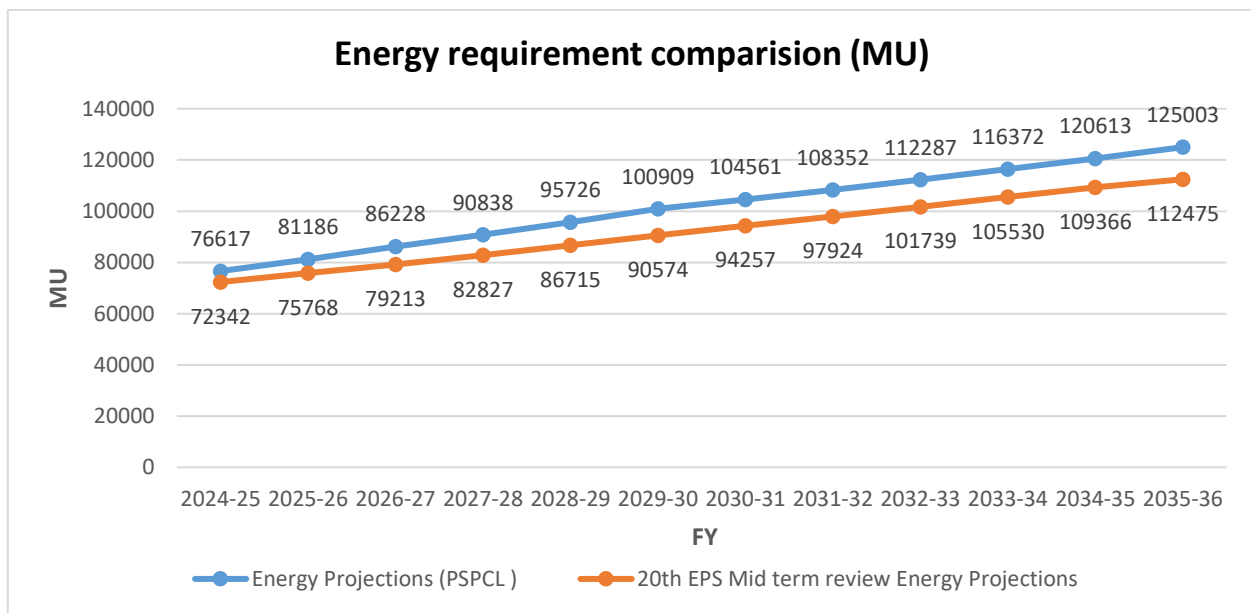


Figure 8 Comparison of Energy Requirement Projections of 20th EPS mid-term vs PSPCL

The energy requirement projections of PSPCL is higher compared to 20th EPS mid-term review. However, the actual energy requirement in FY 2024-25 is 77,423 MUs which is significantly higher compared to 20th EPS mid-term review. Therefore, the peak demand and energy requirement projections from PSPCL have been considered.

- ii) Future demand profile till the year 2035-36 has been projected using the demand profile for the year 2024-25 as the base profile.
- iii) The actual solar, wind and hydro generation profiles and CUFs have been considered from actual generation (as provided by PSPCL) and National Electricity Plan 2023 (Vol I Generation).
- iv) The capital costs of candidate plants for coal, wind, solar, and storage 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 CEA and as furnished by PSPCL.

Table 8 Source wise planned capacity addition (MW)

FY	COAL	NUCLEAR	BIOMASS	HYDRO	SOLAR	PSP	Storage (MW/ MWh)	DRE Solar
2025/26	0	0	0	131	3254	0	0	120
2026/27	0	0	0	70	2600	0	0	105
2027/28	0	0	0	23	0	0	0	70
2028/29	650	0	0	0	0	0	0	70
2029/30	0	0	0	0	0	0	0	70
2030/31	267	0	0	0	0	0	0	70
2031/32	133	0	0	0	0	0	0	70
2032/33	0	0	0	0	0	0	0	70
2033/34	0	0	0	0	0	0	0	70
2034/35	0	0	0	0	0	0	0	70
2035/36	0	0	0	0	0	0	0	70
Total	1050	0	0	224	5854	0	0	855

- vi) **Renewable Purchase Obligation (RPO) trajectory:** Ministry of Power vide 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 9 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.	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 10 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.	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 %			4.5 %	45.00 %
8.	2031-32	41.5 %			4.5 %	46.00 %
9.	2032-33	42.3 %			4.5 %	47.00 %
10.	2033-34	43.0 %			4.5 %	47.50 %
11.	2034-35	43.5 %			4.5 %	48.00 %
12.	2035-36	44.0 %			4.5 %	48.50 %

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 11 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.	2025-26	1177	990	22927	1705	26799
2.	2026-27	1699	1155	25817	2328	30999
3.	2027-28	2225	1290	28741	2998	35254
4.	2028-29	2824	1359	31685	3733	39592
5.	2029-30	3511	1342	34329	4541	43724
6.	2030-31	42347			4705	47052
7.	2031-32	44966			4876	49842
8.	2032-33	47497			5053	52550
9.	2033-34	50040			5237	55277
10.	2034-35	52466			5428	57894
11.	2035-36	55001			5625	60626

Table 12 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	26799	33.01%	26972	33.22%	0.21%
2026/27	30999	35.95%	37939	44.00%	8.05%
2027/28	35254	38.81%	38277	42.14%	3.33%
2028/29	39592	41.36%	38415	40.13%	-1.23%
2029/30	43724	43.33%	38429	38.08%	-5.25%
2030/31	47052	45.00%	38442	36.76%	-8.24%
2031/32	49842	46.00%	38445	35.48%	-10.52%
2032/33	52550	47.00%	38448	34.24%	-12.76%
2033/34	55277	47.50%	38452	33.04%	-14.46%
2034/35	57894	48.00%	38470	31.90%	-16.10%
2035/36	60626	48.50%	38470	30.78%	-17.72%

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 has been carried out considering only the existing and planned capacity contracts. The total unserved energy for the year 2035-36 has been estimated as 26,730 MU. The year-wise likely unserved energy with the planned capacities is given in the figure.

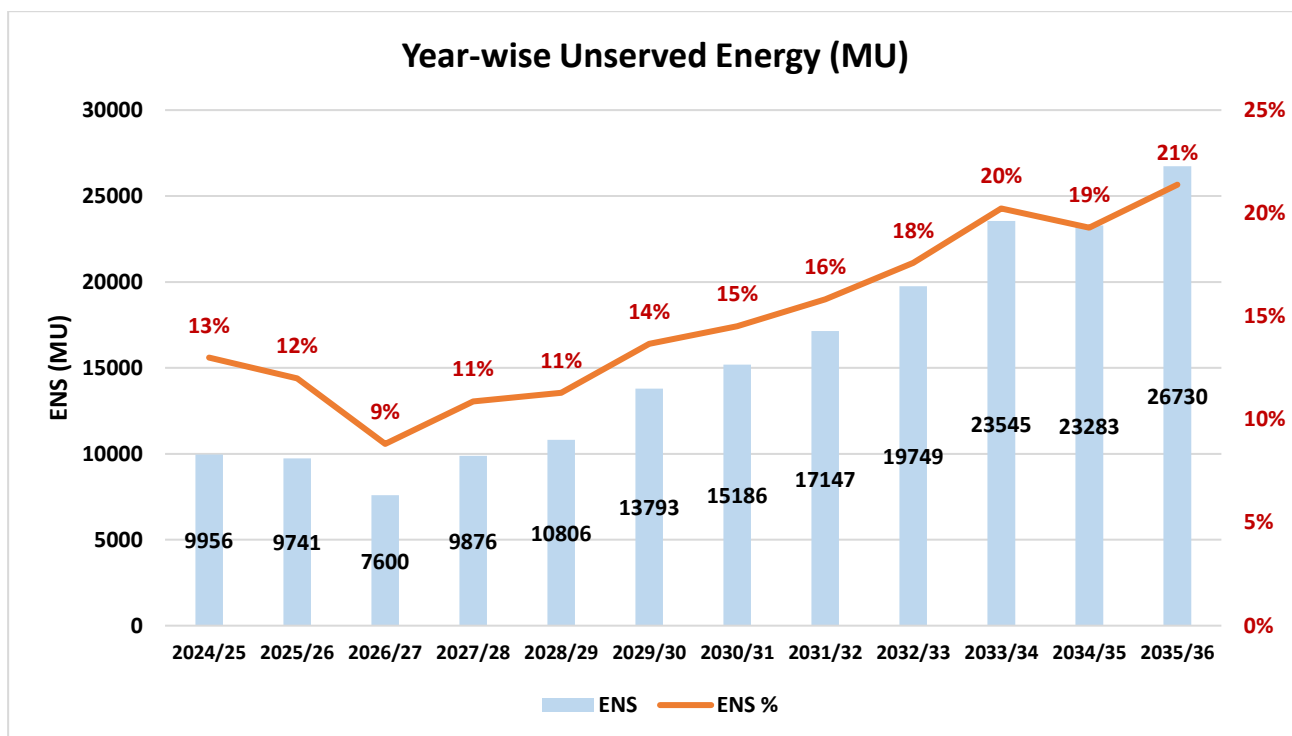


Figure 9 Yearly likely unserved energy (in MU) with the existing and planned capacities

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 projected electricity demand.

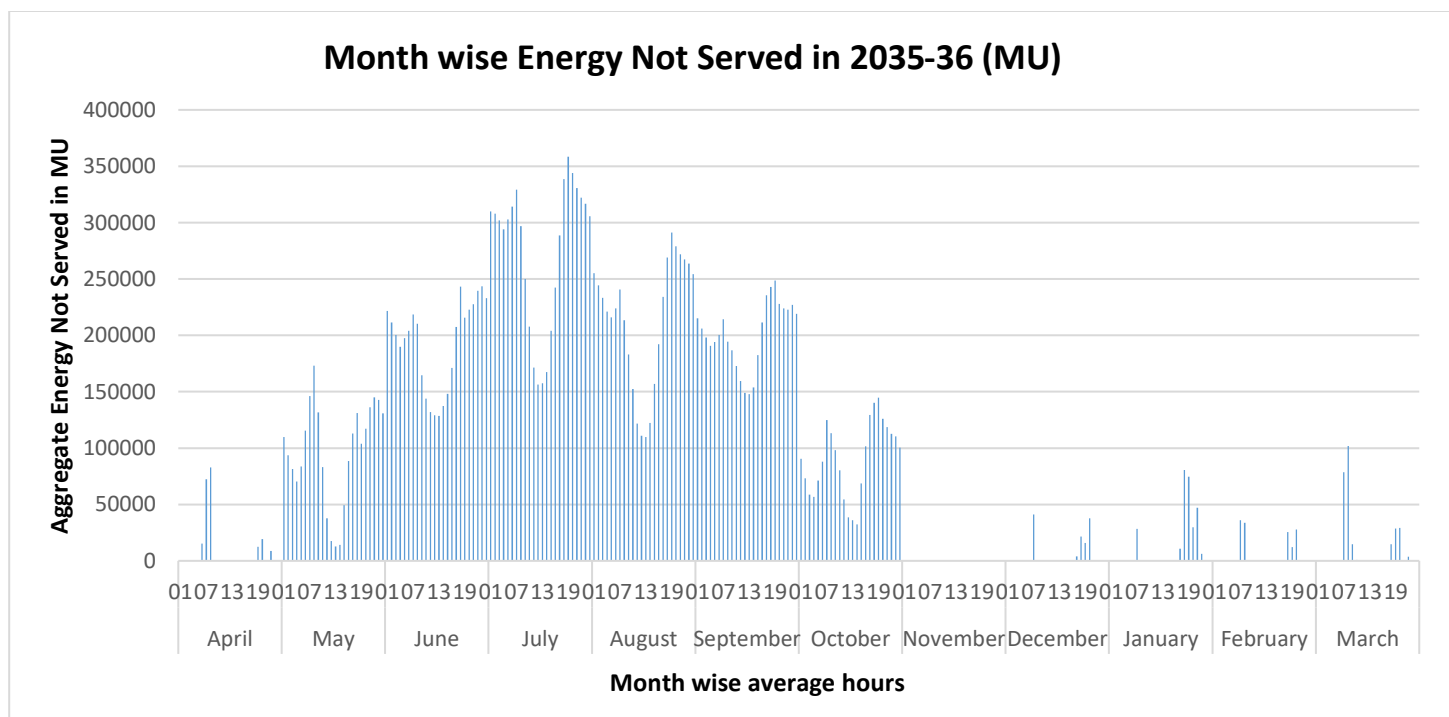


Figure 10 Block-wise Unserved Energy Pattern GWh (2035-36)

The unmet demand occurs during both solar and non-solar hours in peak months. Additionally, the state is expected to face unmet demand during non-solar hours from January to March.

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 Punjab are given below:

Table 13: Year-wise contracted capacity projections (in MW)

Year	Coal	Gas	Nuclear	Biomass	Hydro	Wind	Solar	DRE	FDRE	Storage	MTOA/ STOA
2025/26	8233	137	197	234	3461	450	4959	973	0	0	6142
2026/27	8233	137	197	234	3591	450	7559	1329	1000	0	5629
2027/28	8303	137	197	234	3661	950	11273	1711	1000	262	5500
2028/29	9453	137	197	234	3684	1450	11273	2131	1000	262	5500
2029/30	9953	137	197	234	3684	1950	11990	2592	1000	762	5500
2030/31	10720	137	197	234	3684	2450	13514	2686	1000	1680	5000
2031/32	11353	137	197	234	3684	2950	13993	2783	1000	1775	5000
2032/33	11853	137	197	234	3684	3450	14109	2884	1000	1812	5212
2033/34	12043	137	197	234	3684	3950	16596	2989	1000	2812	5200
2034/35	12043	137	197	234	3684	4450	16596	3098	1000	2812	4205
2035/36	12043	137	197	234	3684	4950	16807	3211	1000	2812	8000

The year-wise storage projection (in MW/MWh) is given below:

Table 14: Year wise storage projections

Year	Storage (4h)	Storage (6h)
2025/26	0	0
2026/27	0	0
2027/28	262/1048	0
2028/29	262/1048	0
2029/30	762/3048	0
2030/31	1262/5048	417/2502
2031/32	1358/5432	417/2502
2032/33	1395/5580	417/2502
2033/34	1895/7580	917/5502
2034/35	1895/7580	917/5502
2035/36	1895/7580	917/5502

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

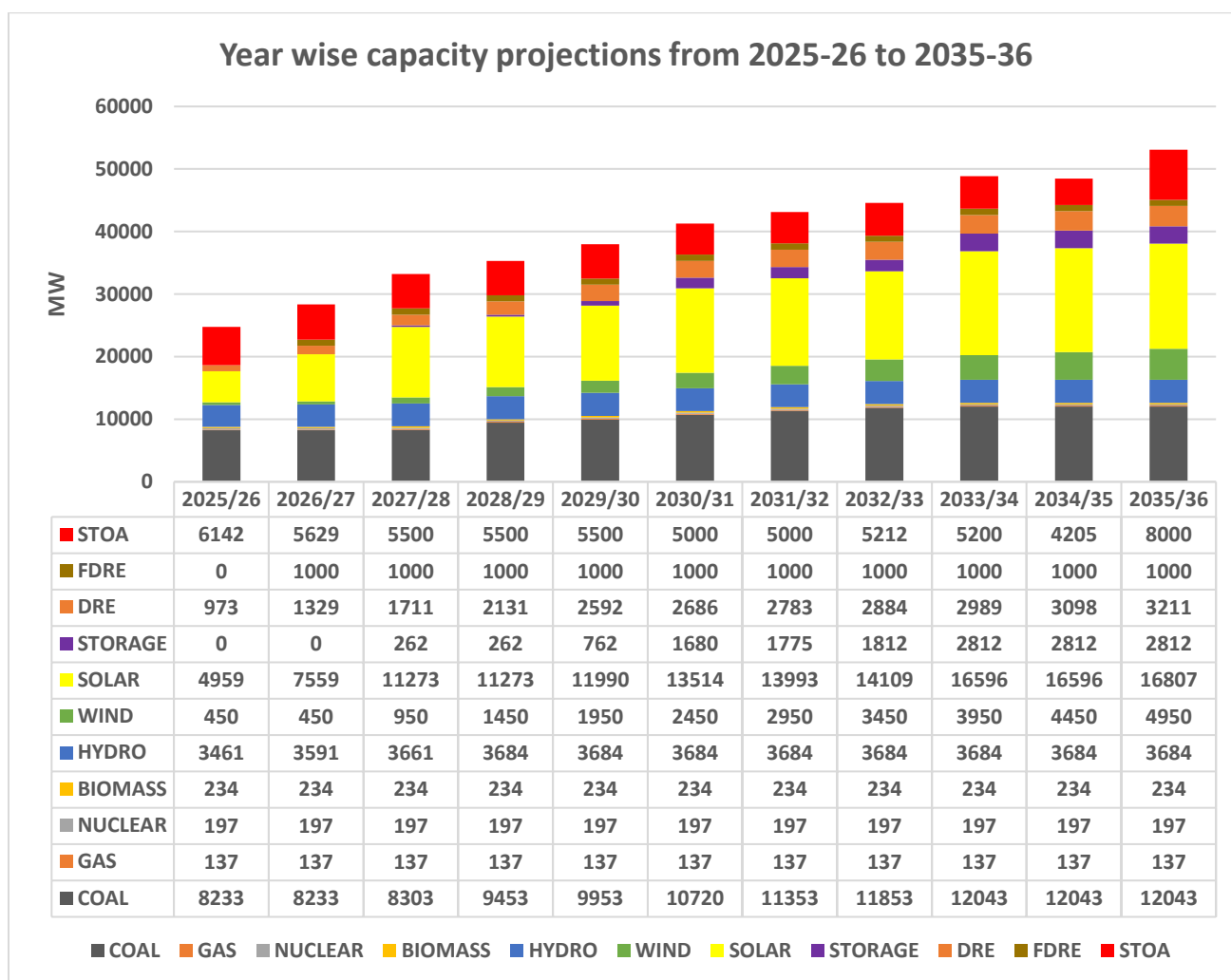


Figure 11 Projected Contracted Capacity Mix Year-wise (MW)

The STOA/MTOA requirement can be fulfilled through power procurement from market 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 Normalised Energy Not Served (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 42,263 MW which consists of 12,043 MW from coal, 137 MW from gas, 197 MW from nuclear, 234 MW from biomass, 3,684 MW from hydro, 4,950 MW from wind, 16,807 MW from solar, 3,211 MW from Distributed Renewable Energy (DRE) sources, 1000 MW of FDRE, 2812 MW/13082 MWh from Storage. Further, in addition to this, 8,000 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 Punjab has been assessed at 11% during Solar hours and 9% during non-solar hours. Furthermore, the projected/contracted capacity is in compliance with the stipulated Renewable Purchase Obligation (RPO) targets.

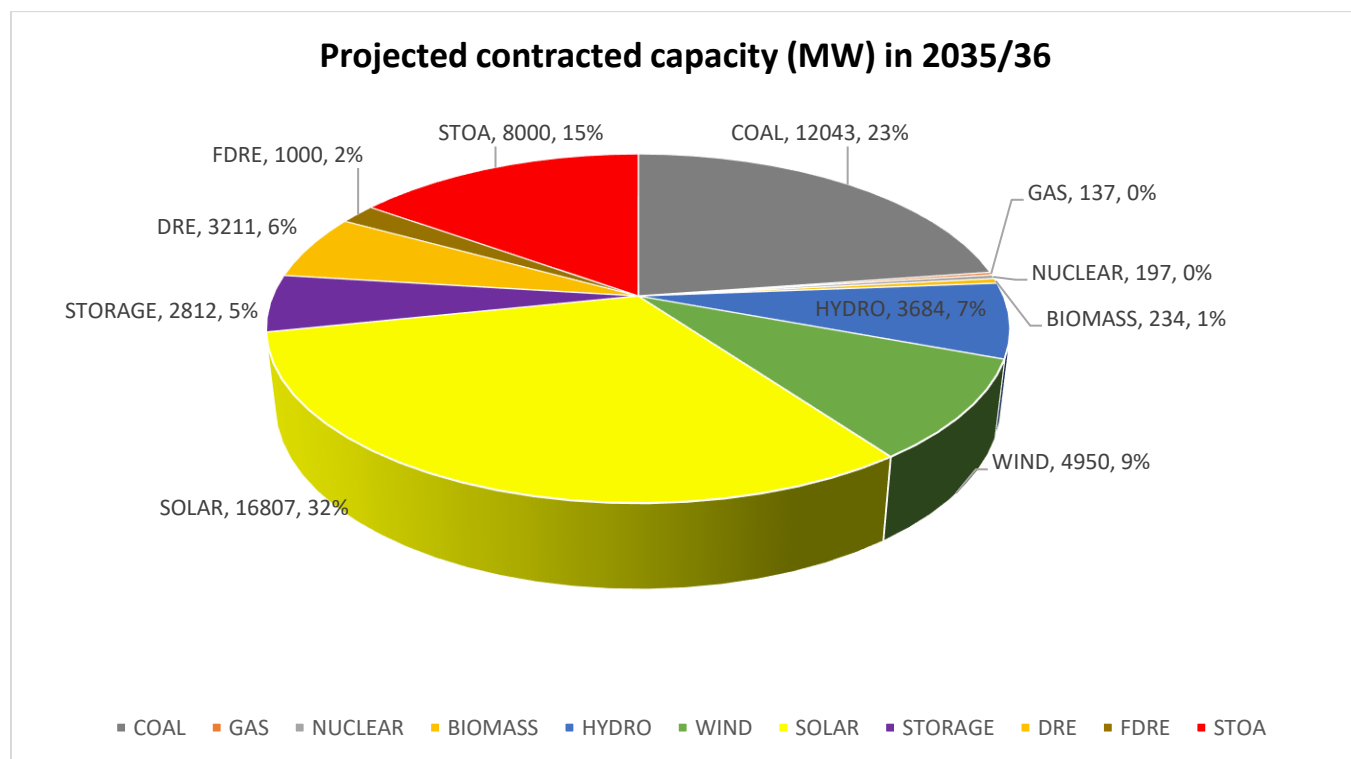


Figure 12 Contracted Capacity Mix in 2035-36 with PRM of 11%

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 15 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	0	0	0	0	131	0
2026/27	0	0	0	0	70	0
2027/28	0	70	0	0	23	500
2028/29	650	500	0	0	0	500
2029/30	0	500	0	0	0	500
2030/31	267	500	0	0	0	500
2031/32	133	500	0	0	0	500
2032/33	0	500	0	0	0	500
2033/34	0	500	0	0	0	500
2034/35	0	0	0	0	0	500
2035/36	0	0	0	0	0	500
TOTAL	1050	3070	0	0	224	4500
	SOLAR		DRE		FDRE	Storage
Year	Planned Contracts	Additional Requirement	Planned Contracts	Additional Requirement	Planned contracts	Additional Requirement
2025/26	3254	0	120	400	0	0
2026/27	2600	0	105	250	1000	0
2027/28	0	3714	70	312	0	262
2028/29	0	0	70	350	0	0
2029/30	0	717	70	391	0	500
2030/31	0	1524	70	24	0	917
2031/32	0	479	70	27	0	95
2032/33	0	116	70	31	0	37
2033/34	0	2487	70	35	0	1000
2034/35	0	0	70	39	0	0
2035/36	0	211	70	43	0	0
TOTAL	5854	9248	855	1902	1000	2812

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

Table 16: Year wise storage addition

Year	Storage (4h)	Storage (6h)
	Additional Requirement	Additional Requirement
2025/26	0	0
2026/27	0	0
2027/28	262/1048	0
2028/29	0	0
2029/30	500/2000	0
2030/31	500/2000	417/2502
2031/32	95/380	0
2032/33	37/148	0
2033/34	500/2000	500/3000
2034/35	0	0
2035/36	0	0
TOTAL	1895/7580	917/5502

The share of non-fossil fuel-based capacity in the generation mix is projected to increase to around 62% by 2035-36 from 32% in 2024-25. The projected gross generation mix for the state is shown in figure:

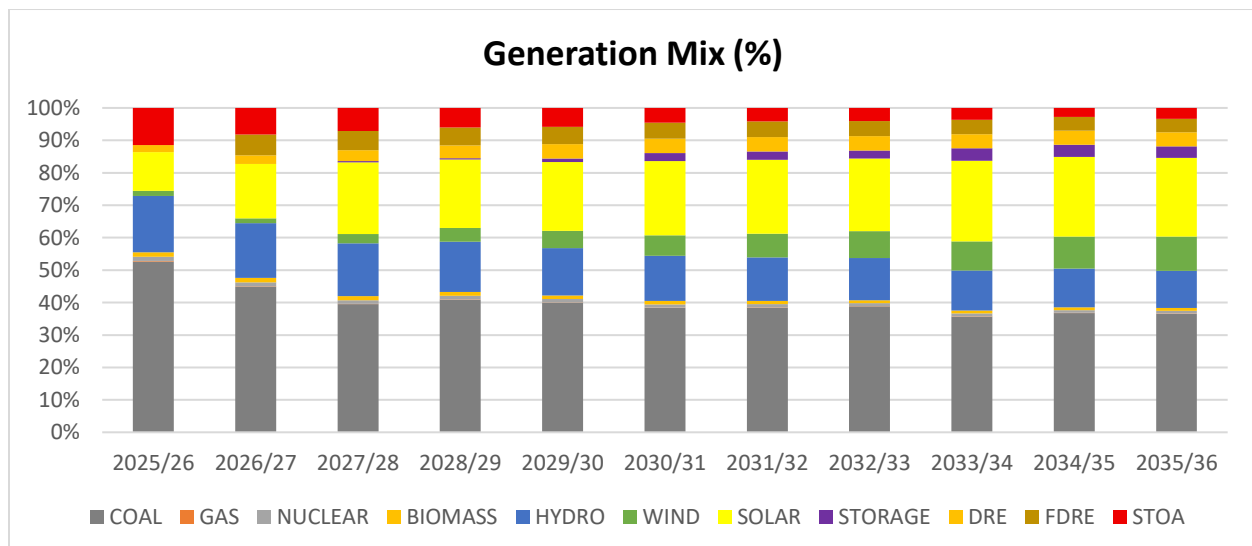


Figure 13 Year-wise projected gross generation mix (in %)

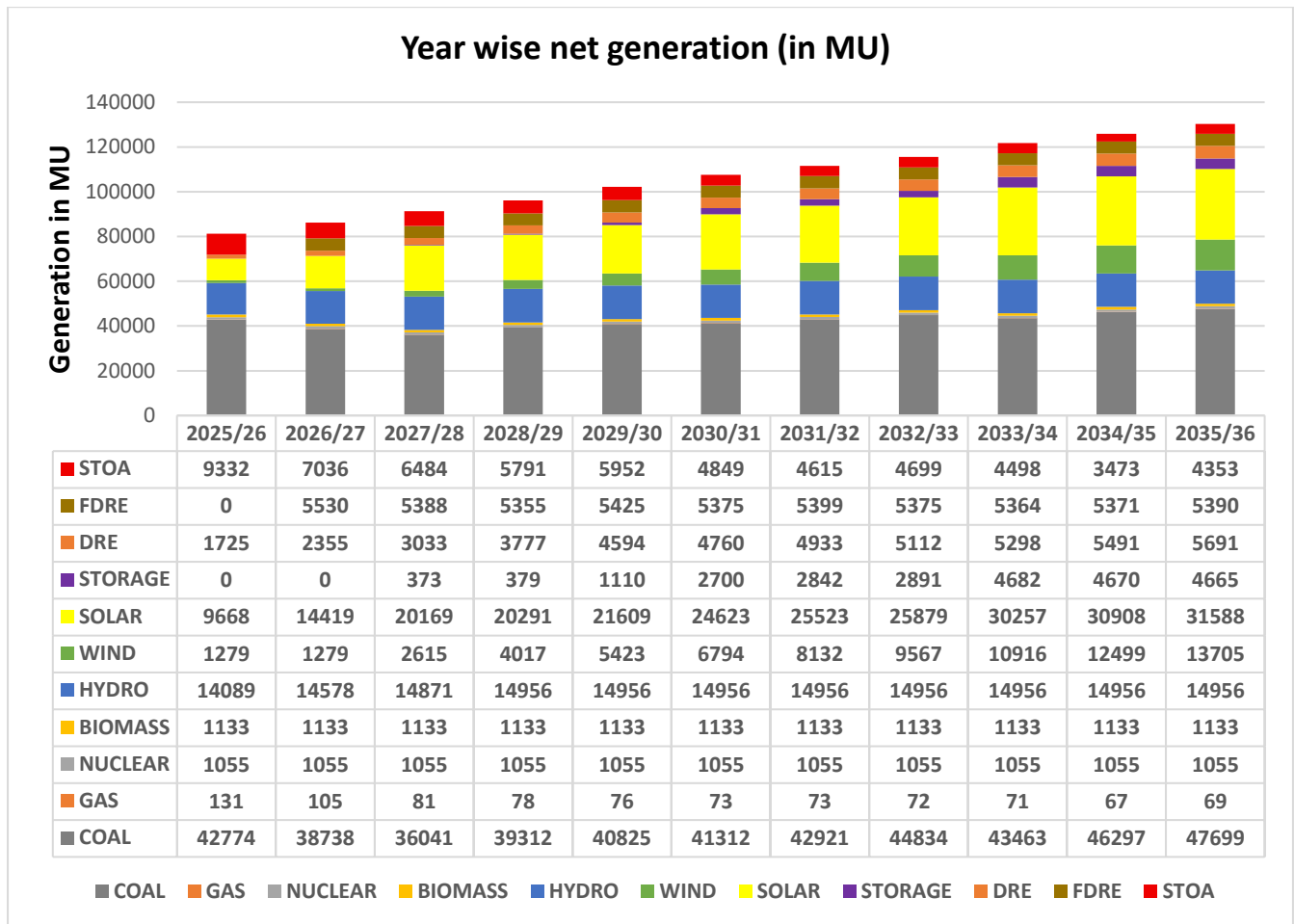


Figure 14 Year-wise projected gross generation (in GWh)

7.3 Coal Capacity Performance

The coal capacity PLF is expected to remain in the range of around 41% - 59% for the years till 2035-36 ensuring higher absorption increasing contracts from renewable energy.

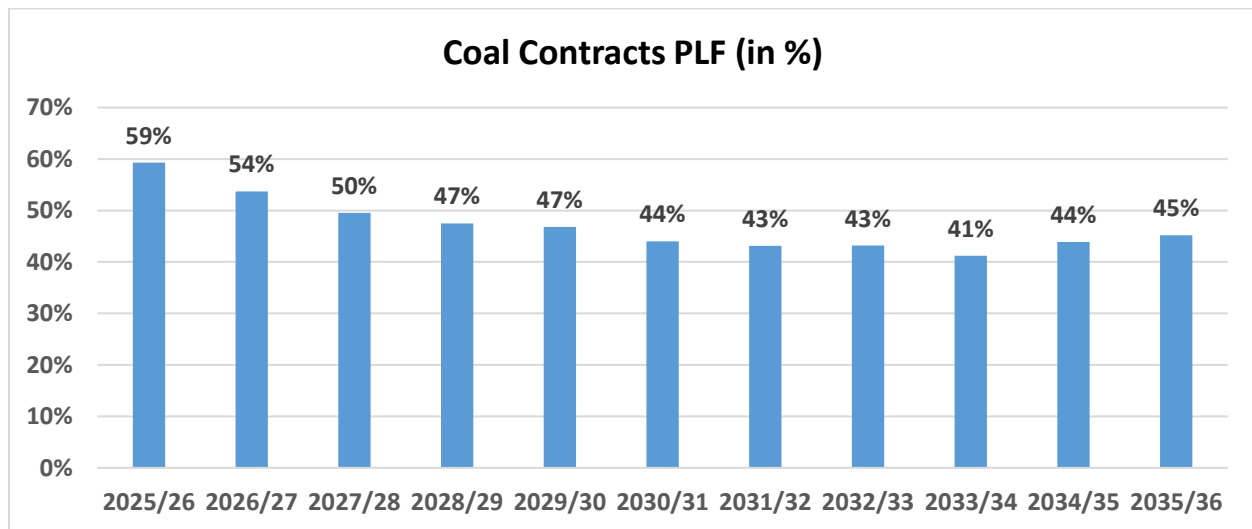


Figure 15 Year-wise coal contracts PLF (in %)

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 is given below. This capacity can be shared with other states/ Discoms and reduce the fixed cost burden on the utility resulting in reduction in the cost to consumer. The state has likely surplus capacity available during October to March months of around 1,800 MW in 2028-29 as shown below which can be shared with other states/ Discoms.

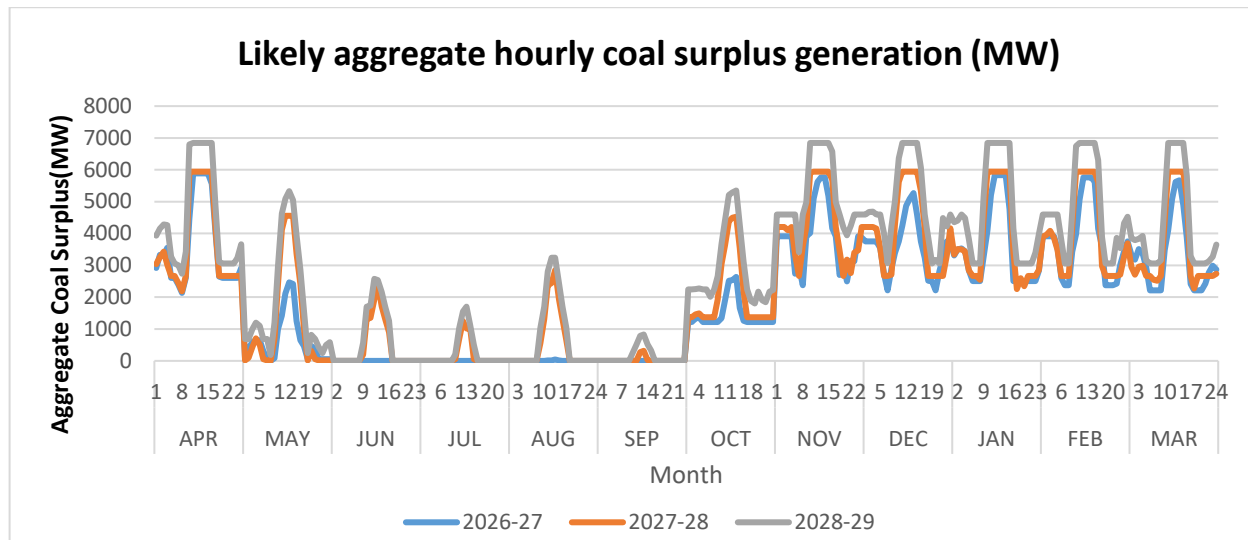


Figure 16 Surplus Coal Capacity Year-wise (MW)

8.0 Conclusions

Based on the Resource Adequacy studies of Punjab 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 2024-25. Based on the demand pattern, it is seen that the peak demand season is typically from June to August with peak demand occurring during solar hours.
2. The study has considered energy requirement projections as per the projections of PSPCL, which envisages that the annual energy requirement of the state is likely to grow at a CAGR of 4.5 % while the peak demand for the utility is likely to grow at a CAGR of 4.7% for the period of 2024-25 to 2035-36.
3. Punjab is likely to witness energy deficit ranging from 9.7 to 26.7 BUs in different years from 2024-25 to 2035-36 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 of about 3070 MW have to be procured by the year 2035-36. In addition to this, the state will likely require MTOA/ STOA arrangement ranging from around 4200 MW

to 8000 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 Punjab has been assessed at 11% during Solar hours and 9% 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 56% of contracted capacity from fossil fuel sources. The share of fossil fuel based capacity is likely to reduce to 28.8% in 2035-36. In 2035-36, the RE based (that includes hydro, solar, wind, biomass and DRE) capacity are likely to constitute around 71% of the total installed capacity.
8. It is likely that Punjab may have surplus capacity available during the months from October to March 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.

Planned Future Contracted (MW) considered in the study

Sr. No.	Tied capacity name	Type of generation	Expected COD	Tentative PSPCL share (in MW)
1.	Teesta-VI	Hydro	2027-28	32
2.	Ratle HEP	Hydro	2028-29	23
3.	Rangit-IV	Hydro	2025-26	12
4.	Kiru	Hydro	2026-27	40
5.	Kwar	Hydro	2027-28	38
6.	Vishnugarh Pipalkoti	Hydro	2026-27	27
7.	New Nabi Nagar, Stage-II	Thermal	2030-31	600
8.	Telangana Stage-II	Thermal	2 units in 2030-31 and 1 in 2031-32	400
9.	Singrauli-III	Thermal	2029-30	50

Assumption for Resource Adequacy Studies

1. Electricity Demand & peak requirement: As per projections made by PSPCL.
2. Demand Profile: Based on hourly demand profile of 2024-25.
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
46 %	32%	20-22%	20%

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	100	-	-	-	-
Solar	Existing/Planned		-	-	-	-	-
	Candidate		-	-	-	-	-

Wind	Existing/Planned	generation profile	-	-	-	-	-
	Candidate		-	-	-	-	-
Pumped storage	Existing/Planned	95	50	-	-	-	-
	Candidate		50	-	-	-	-
Storage 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	-	-		-	-	-	-	-
Storage 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
Storage (2-Hour)	5.13 Cr to 3.13 Cr	1 % of Capex	0.5	14
Storage (4-Hour)	8.22 Cr to 4.72 Cr	1 % of Capex	0.5	14
Storage (5-Hour)	9.77Cr to 5.51 Cr	1 % of Capex	0.5	14
Storage (6-Hour)	11.31 Cr to 6.30 Cr	1 % of Capex	0.5	14