APRIL 2023

REPORT ON OPTIMAL GENERATION MIX 2030 VERSION 2.0

GOVERNMENT OF INDIA
MINISTRY OF POWER
CENTRAL ELECTRICITY AUTHORITY

सत्यमेव जयते

REPORT ON OPTIMAL GENERATION CAPACITY MIX FOR 2029-30

Version 2.0

APRIL 2023

GOVERNMENT OF INDIA

MINISTRY OF POWER

CENTRAL ELECTRICITY AUTHORITY

Disclaimer

The study is an exercise to assess the least cost generation capacity mix to meet the projected Electricity Demand for the year 2029-30. The projected installed capacity shown in the report should not be in any way considered as target of the country. The study is based on numerous assumptions in respect of technical and financial variables associated with various power generation technologies. Any change in assumptions considered may vary the result.

घनश्याम प्रसाद
अध्यक्ष तथा पदेन सचिव भारत सरकार
GHANSHYAM PRASAD
Chairperson & Ex-officio Secretary
To the Government Of India

सत्यमेव जयते

आज़ादी का अमृत महोत्सव

केन्द्रीय विद्युत प्राधिकरण
भारत सरकार
विद्युत मंत्रालय
सेवा भवन, आर.के. पुरम
नई दिल्ली–110066
Central Electricity Authority
Ministry of Power
Sewa Bhawan, R. K. Puram
New Delhi-110066

FOREWORD

India is a developing country with growing energy needs. The increasing per capita consumption of electricity is a strong indicator of the growth trajectory of the country. Availability of affordable and reliable electricity is a key factor in sustainable growth of the country.

The huge potential of growth in power sector necessitates a detailed study of optimal use of resources available in the country to meet its growing electricity demand. This updated version of the report on optimal generation capacity mix for the year 2029-2030 fulfills this purpose, by providing perspective towards a cost effective energy security as well as environment friendly solution to meet electricity demand of the country.

The report provides roadmap for energy transition through decarburization of power sector, in the country, by giving emphasis to renewable energy and energy storage systems. With high renewables penetration in the system, India can comfortably meet its Nationally Determined Contribution target of 50% non-fossil fuel capacity.

I appreciate the efforts put in by Smt Ammi Ruhama Toppo, Chief Engineer (IRP), CEA and her team of officers in bringing out updated report, which will enable setting up of suitable system and policies to optimally utilize the generation resources in coming years, in order to ensure the affordable and reliable supply of electricity to every citizen of this country.

(**Ghanshyam Prasad**)

दूरभाष / Telephone : 011-26732201, 26732222, ईमेल / Email : chair@nic.in, वेबसाईट / Website : www.cea.nic.in

सत्यमेव जयते

A Balan

Member (Planning)
Central Electricity Authority

PREFACE

The report on "Optimal generation capacity mix for the year 2029-30 (Version 2.0)" has been prepared by carrying out detailed generation expansion planning studies for the year 2029-30 to look into the possible growth scenarios in Indian power sector in the near future.

A State-of-the-art sophisticated generation expansion planning model has been used to carry out the studies which include both long term studies as well as hourly dispatch studies. The report has projected a total installed capacity in the country of around 777 GW in the year 2030 with a battery energy storage of 41 GW. The projected gross electricity generation (BU) during the year 2029-30 is likely to be 2440 BU comprising of 1363.5 BU from Thermal (Coal, Gas and Lignite), 1076 BU from Non Fossil Sources (including 212 BU from Hydro, 208 BU from Wind,553 BU from Solar, 92.2 BU from Nuclear,10 BU from Other RE). The share of Non Fossil Fuel based sources is going to increase to 64% in 2029-30 from present level of 42% of total installed capacity. Similarly in terms of gross generation the share of Non fossil fuel sources is going to increase up to 44% in 2029-30 from 25% in 2022-23.

The short term (Hourly Dispatch) studies indicate that the above capacity is adequate to meet the demand at every instant of time during the year 2029-30 fulfilling all the technical constraints associated with various generation technologies. Several scenarios were studied to assess the capacity addition requirement to meet the projected demand in the year 2029-30. It is seen that apart from under construction coal based capacity of 27 GW, the additional coal based capacity required till 2030 may vary from 12.7 GW to around 19.1 GW across various scenarios. It is also seen that the BESS requirement in 2030 is varying from 22.6 GW/113.1 GWh to 49.3 GW/246.9 GWh across different scenarios studied.

I convey my sincere thanks to Smt A. R. Toppo, Chief Engineer and all the officers of Integrated Resource Planning Division, CEA for successfully carrying out a comprehensive study and coming up with this updated report which will give the reader a holistic idea and understanding of likely growth trajectory of Indian power sector in coming years.

(A.Balan)

सत्यमेव जयते

Ammi Ruhama Toppo

Chief Engineer

IRP Division

Central Electricity Authority

ACKNOWLEDGEMENT

The preparation of report on optimal generation capacity mix in the year 2029-30 would not have been possible without the expert guidance of Chairperson, CEA and Member (Planning), CEA.

I am thankful to various stakeholders in the power sector who have given their valuable suggestions and words of encouragement towards finalization of the report.

I am also thankful to the dedicated team of Integrated Resources Planning division, CEA for their tireless efforts in carrying out generation expansion planning studies and preparing this report. The specific contribution made by following officers of IRP division is well appreciated and acknowledged with thanks:-

1. Sh. Jitendra Kumar Meena — Director
2. Sh. Apoorva Anand — Deputy Director
3. Ms. Jyotsana Kapoor — Deputy Director
4. Sh. Rahul Kumar — Assistant Director
5. Sh. Himanshu Nagpal — Assistant Director
6. Sh. Girija Sankar Pati — Assistant Director

(Ammi Ruhama Toppo)

Executive Summary

India has emerged as a major force in the global energy economy. As the world is grappling with the challenge of climate change, India is committed towards reducing its carbon footprint in line with the global response to tackle this challenge. India's approach of growth in power sector is resonating with the global demand of shift towards green generation. In this regard, India stands committed to reduce Emissions Intensity of its GDP by 45 percent by 2030, from 2005 level and achieve about 50 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030.

Between 2005 and 2022, per capita electricity consumption doubled from 631 Unit to 1255 Unit in India, making it the third largest electricity market in the world. With the onset of Covid-19 pandemic the pace of energy development of the country slowed down temporarily. However, the actual power scenario observed during April & May of FY 2022-23 is indicating return to normalcy from Covid pandemic as power consumptions are higher than the trends witnessed in the recent past. With steady economic growth expected there is much scope of the Demand to rise.

To move towards a Carbon free future, the world today is witnessing several kinds of technological disruptions which may lead to replacement of thermal based generation with renewable energy generation complimented with energy storage technology. This has been further aided by the downward trend of cost of solar panels and newer technology options like battery energy storage systems. To meet the target of achieving 50% of non-fossil fuel-based IC by 2030, large scale integration of variable renewable energy sources is envisaged. The RE based generation is inherently intermittent and non-dispatchable in nature. This would in turn require balancing by the conventional power generators to manage the variable RE based generation. As coal-based generation being inherently inflexible in nature, multipronged approach including use of pumped storage plant and battery storage, cyclical operation of Gas based generation, optimisation of hydro generation, etc. would be needed to ensure secure and reliable operation of the grid.

The demand projections of 20th EPS report have been considered for this report, wherein the impact of various factors like reduction in transmission & distribution losses, energy efficiency improvement measures, production of green hydrogen, penetration of electric vehicles, roof-top solar, solar pumps etc. has appropriately been considered on the demand of the country in the future.

Furthermore, Hon'ble Prime Minister launched the National Hydrogen Mission on India's 75th Independence Day where in it is envisaged to make India a green hydrogen hub with the target of production of 10 million tonnes of green hydrogen by 2030. This has been duly accounted for while making the demand estimates for 2029-30.

Keeping in view the recent developments and policy changes in the electricity sector both at global and national level since the publication of original report, generation planning studies have been revised to obtain the least cost optimal generation capacity mix which may be required to meet the projected peak electricity demand and electrical energy requirement of the year 2029-30.

The study as before minimizes 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 earlier report was based on consideration of a single node for the country with no transmission constraints in between the various regions. In this report, study has been carried out considering 5 nodes corresponding to each of the five regions of the country.

The hourly studies have been carried out to assess adequacy of the capacity mix obtained from long term generation planning studies for the year 2029-30. All the technical/operational characteristics of each individual generating unit have been adhered to arrive at the adequacy of the generation capacity mix at least production cost.

Table of Contents

ACRONYMS

ACRONYMS	EXPANSION
BESS	Battery Energy Storage System
BMS	Battery Management System
BU	Billion Unit
CAGR	Compound Annual Growth Rate
CERC	Central Electricity Regulatory Commission
CO_2	Carbon dioxide
CUF	Capacity Utilization Factor
EMS	Energy Management System
EPS	Electric Power Survey
GCF	Green Climate Fund
GDP	Gross Domestic Product
GW	Giga Watt
INDC	Intended Nationally Determined Contribution
KGD6	Krishna Godavari Dhiru bhai 6
kWh	kilowatt hour
LNG	Liquefied Natural Gas
LWR	Light Water Reactor
MGR	Merry Go Round
MNRE	Ministry of New and Renewable Energy
MT	Million Tones
MU	Million Unit
MW	Mega Watt
NEP	National Electricity Plan
O&M	Operation and Maintenance
PHWR	Pressurized Heavy Water Reactor
PLF	Plant Load Factor
PV	Photo Voltaic
RE	Renewable Energy
RLNG	Re-gasified Liquefied Natural Gas
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction

Central Electricity Authority had carried out "Optimal generation capacity mix studies for the year 2029-30". The report was published in January 2020. The objective of the report was to find out the least cost optimal power generation capacity mix, which may be required to meet the peak electricity demand of 340 GW and electrical energy requirement of 2400 BU by the year 2029-30 as per 19^{th} Electric Power Survey.

Since the publication of the report, many assumptions have changed both at global and national level. The 20^{th} Electrical Power Survey report has revised the projected peak electricity demand and electrical energy requirement for the year 2029-30.

With the onset of Covid-19 pandemic the pace of energy development of the country has taken a hit. The local businesses as well as world trade and movements have been affected to varying degrees by the pandemic. The generation capacity addition by different sources has got adversely affected in the short run with lasting impacts. The strict lockdown to arrest the pandemic, halted the constructions activities due to a lack of manpower and supply chain issues. Delay in manufacturing and installation of various projects due to disruption in the global supply chain led to difficulties with the availability of key components leading to delays in execution of projects. For instance, solar segment manufacturing companies faced delays in the procurement of material. As a result, the capacity of conventional and RE sources which was under construction has been delayed. Therefore, underlying data like status of under construction plants of coal, hydro and RE plants, new proposed nuclear and hydro plants, cost trajectories of Battery Energy Storage Systems (BESS) has changed since the report was published in 2020.

The world is actively addressing the threat of climate change and therefore the idea of growing sustainably is taking prominence globally. In view of this, all countries across the globe have been actively engaged in climate negotiations on different platforms viz. UNFCCC. Towards realizing the objective of carbon free energy, India has updated its Nationally Determined Contributions (NDCs) according to which it stands committed to reduce Emissions Intensity of its GDP by 45 percent from 2005 level by 2030, and to achieve about 50 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030.

In view of the above-mentioned aspects, the "Optimal generation capacity mix for the year 2029-30" study has been revised.

2. Context –Changes incorporated in revised version

The report published in January 2020 projected the least cost optimal generation capacity mix for the year 2030 based on the 19th EPS projections. As per the earlier study, the likely installed capacity by the end of 2029-30 was projected as 8,17,254 MW comprising of Hydro 60,977 MW (including Hydro Imports 5,856 MW), Pumped Storage Plants 10,151 MW, Small Hydro 5,000 MW, Coal 2,66,911 MW, Gas 25,080 MW, Nuclear 18,980 MW, Solar 280,155 MW, Wind 140,000 MW and Biomass 10,000 MW along with a Battery Energy Storage capacity of 27,000 MW/108,000 MWh to meet the projected peak electricity demand of 340 GW and electrical energy requirement of 2400 BU as per the 19th EPS report. The projected installed capacity from RE sources excluding large hydro (Solar, wind, biomass and small hydro) in the year 2029-30 was projected as 435 GW.

Following are the broad assumptions, which have been revised in the studies:

2.1. Demand Projections

The latest demand projections, as per the 20th EPS report, have been considered for the studies. It is emphasized that while projecting the electricity demand, the impact of various factors like reduction in transmission & distribution losses, energy efficiency improvement measures, production of green hydrogen, penetration of electric vehicles, roof-top solar, solar agriculture pumps, electrification of households etc. has appropriately been considered in 20th EPS projections. The major highlights of the 20th EPS projections are:

- Projected a peak electricity demand of 334.8 GW and electrical energy requirement of 2279.7 BU for the year 2029-30.
- The impact of EVs on all India Demand in 2029-30 is likely to be 3 GW in Peak Demand and 15 BU in Energy requirement.
- All India energy requirement off set due to Solar Roof Top installation has been estimated as 34.8 BU in 2029-30.
- All India energy requirement off set due to Solar pump installation has been estimated as 2.4 BU in 2029-30.
- Additional energy requirement for the country on account of green hydrogen production of around 10 million Tonnes (considering only 5 million tonnes load on Grid) has been estimated as 250 BU by FY 2029-30.

2.2. Five regional nodes

The study has considered 5 regional grids, i.e., NR, WR, SR, ER and NER connected through inter-regional transmission links. A node has been created representing each of the 5 regions and these nodes have separate demand profiles and RE generation profiles of solar and wind resources.

2.3. Planned and Candidate Capacity

2.3.1 Coal

As per the latest assessment carried out by CEA, the coal capacity, which is under construction and is expected to be commissioned during 2022 -30, is around 26,900 MW. Pit head based potential supercritical coal capacity totaling to 21,240 MW has been considered for investment options (candidate plants) in the modeling studies based on list of potential candidate plants which are either in development stages or are proposed to be set up by various Central and State utilities. It may be noted that out of this a coal capacity totaling to 6,920 MW is under bidding (as on 28.02.23).

Additionally, coal-based capacity of Central and state sector utilities, totaling to 9,420 MW which has been identified to be considered for development in future, if required, has been also taken into consideration for the studies.

The Capex for new coal plants has been considered as Rs 8.34 Cr/MW (up from 7.85 Cr/MW considered in the earlier studies) as per the latest inputs provided by various manufacturers/developers.

2.3.2 Hydro (including PSP)

As per the latest assessment carried out by CEA, the Hydro capacity, which is under construction and likely to yield benefits during 2022-30 of around 14,274 MW (including 2780 MW of PSP) is considered for the studies.

Location specific hydro and PSP projects totaling to 638 MW and 11460 MW respectively, which have been either concurred by CEA or are under S&I stage and are likely to yield benefits by 2029-30, have been considered as investment options (candidate plants) for the studies.

The capex and the technical parameters of the planned and candidate hydro projects have been taken from the DPRs (Detailed Project Reports) of the respective power projects.

2.3.3 Nuclear

As per the latest assessment by Dept. of Atomic Energy (DAE), 8700 MW capacity is under construction and 7000 MW capacity addition has been accorded in principle approval. However, only capacity under construction (8700 MW) is likely to be achieved by 2029-30 and hence the same has been considered for the studies for the period of 2022-30.

2.3.4 Solar and Wind based Capacity

In the studies, region-wise solar and wind-based candidate capacity has been considered based on latest state level potential furnished by Ministry of New and Renewable Energy.

MNRE has indicated that cumulative installed capacity of up to 100 GW may be achieved by 2029-30 from wind-based projects and this has been modelled as a constraint for the studies.

As per the MNRE strategy paper, offshore wind power capacity is expected to be added only after 2030 and therefore no offshore wind-based capacity is considered for the period of 2022-30 in the studies.

2.4. Retirement of coal-based capacity

The coal-based capacity of 2,121.5 MW, which are likely to be retired due to non-submission of any FGD installation plan to abide by the new environmental reforms have been considered to be retired till 2029-30. It may be noted that out of this, a capacity of 304 MW has already retired during the year 2022-23.

2.5. Battery Energy Storage System (BESS)

Region-wise BESS investment options have been considered in the studies for the period of 2022-30. Different BESS sizes i.e., 2- hour, 4-hour, 5-hour, 6-hour have been considered for the plan period.

Cost of battery energy storage has been obtained from latest projections available from various manufacturers. The capital cost of the battery has been adjusted to account for the constraint of 90% depth of discharge. It may be noted that the increase in cost due to custom duty, taxes, etc. have been duly considered while carrying out the studies based on recommendation of sector experts.

2.6. Inter-Regional Transmission lines

Existing Inter Regional Transmission links with their available power transfer capacity (as on 31st March, 2022) have been considered in the studies. Candidate inter-regional transmission lines with capital cost have been modelled so that generation and transmission systems can be optimized simultaneously on regional basis keeping in view the availability of generation and transmission resources.

3. Objective of the Study

To find out the optimal generation capacity mix to meet the projected regional peak electricity demand and electrical energy requirement in the year 2029-30 considering possible/feasible technology options, intermittency associated with renewable energy sources and constraints, if any, etc.

Optimum generation mix study is an optimization problem for generation expansion planning, in which the objective function is to minimize:

a. The costs associated with operation of the existing and committed (planned and under construction) generating stations.

b. The capital cost and operating cost of new generating stations required for meeting peak electricity demand and electrical energy requirement while satisfying different constraints in the system such as:

- Fuel availability constraints.
- Technical operational constraints viz. Minimum Power Load of thermal units, ramp rates, startup and shut down time etc.
- Financial implications arising out of startup cost, fuel transportation cost etc.
- Intermittency associated with renewable energy generation.

Technologies/Fuel options available for power generation considered in the study are:

- Conventional Sources – Coal and Lignite, Large Hydro, Nuclear, Natural gas.
- Renewable Energy Sources- Solar, Wind, Biomass, Small Hydro, etc.
- Storage Technologies – Grid scale battery energy storage systems, Green Hydrogen based storage cells, etc.

Note: Various new technologies that may play an important role in power generation in future have not been considered in the present study as they are in nascent stages of development and there is lack of reliable projections regarding their financial and technical parameters.

4. Generation Capacity mix of the country over the years

Generation capacity mix of the country has undergone significant changes since the time of independence with increased electricity demand in the country. Share of hydro capacity, which was about 26% by the end of 10th plan period (i.e.,2006-07), has come down to about 11 % presently (March,

2023) whereas the solar and wind capacity has increased to 26% as of March, 2023 from 9% by the end 2011-12. The share of coal (and lignite) based capacity has also reduced marginally from 56% at the end of 2011-12 to 51% as of March, 2023. The reason of higher percentage of coal-based capacity in the generation capacity mix has been the abundant availability of domestic coal, shorter gestation period and lower capital cost of coal-based plants compared to hydro and nuclear plants.

With the enactment of Electricity Act, 2003, coal-based capacity addition further got a boost with increased participation of private sector in the generation segment. Share of private sector in the installed capacity of the country was about 10% before the Electricity Act, 2003, which has grown to about 50.5% by the end of FY 2022-23. Gas based generation, which also started picking up with new finds of domestic gas, has however slowed down with the reducing production of KG-D6 gas. A significant capacity is presently stranded due to lack of availability of domestic gas and high cost of imported LNG. The country's installed capacity mix has seen growth in nuclear-based capacity from 4th five-year plan onwards which has grown up to 1.6% of the installed capacity as on March, 2023 and there are plans to increase this share further.

Exhibit 4.1 and **Exhibit 4.2** depict the capacity and generation mix historically. It can be seen that the share of hydro in installed capacity has reduced in recent years, though the share of renewable energy has increased. However, in view of increasing share of variable renewable sources (wind and solar) in the system, hydro power plants with storage are the best option to address the intermittency of renewables as they have capabilities of fast ramping-up and ramping -down.

Exhibit 4.1

Installed capacity mix of the country since the year 1980

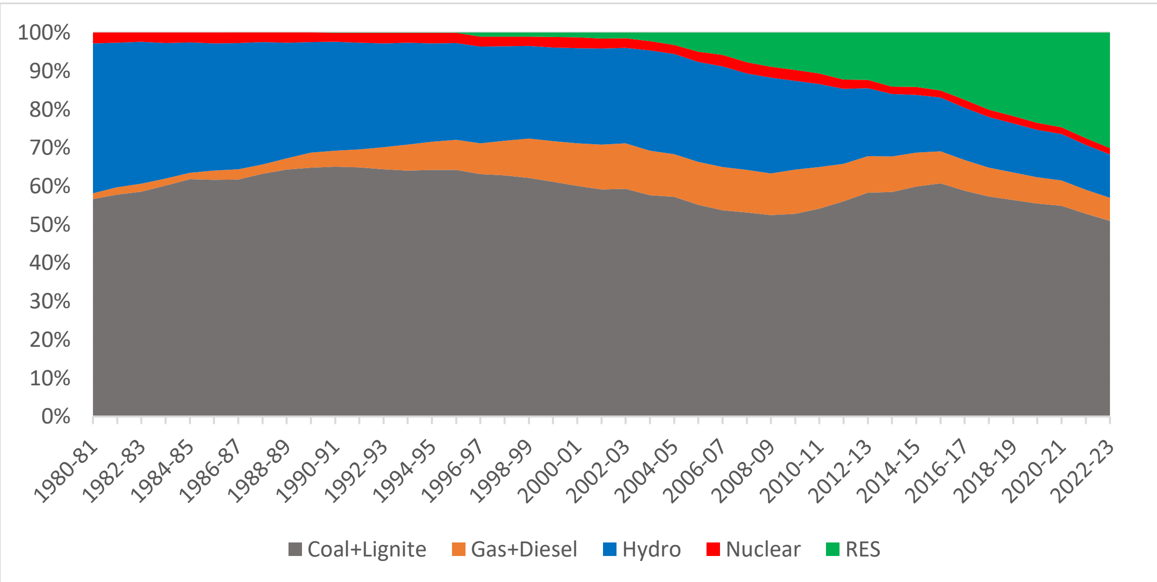
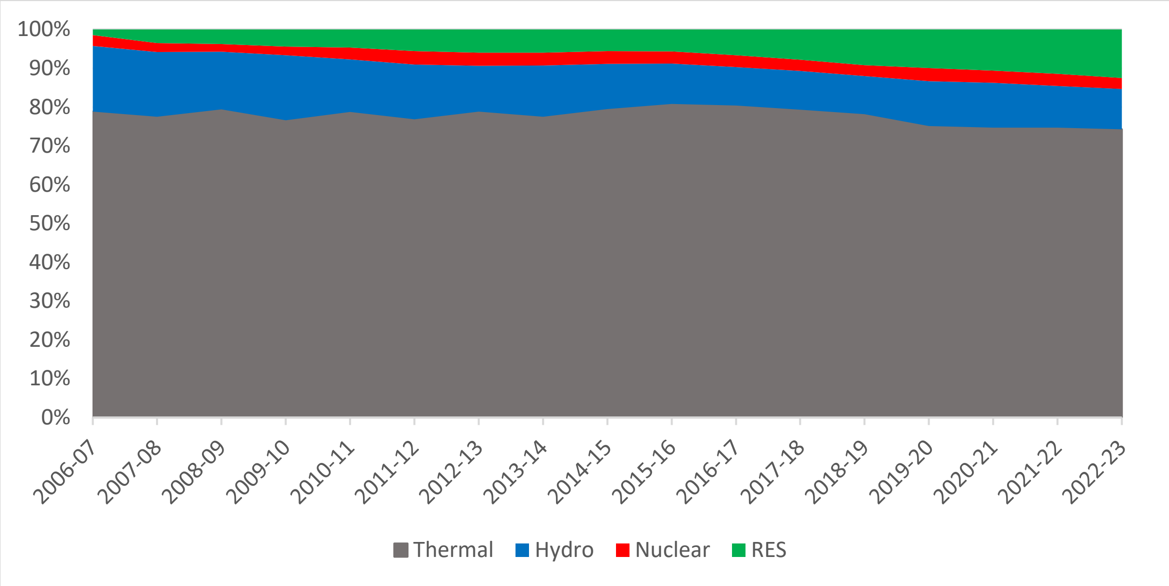


Exhibit 4.2

Generation mix of the country since the year 2006



5. Present Installed Capacity

As on March 2023, the installed capacity of the country was 415.4 GW, which comprises of 236.68 GW from Thermal (211.8 GW Coal + Lignite & 24.8 GW Gas), 6.78 GW from Nuclear, 171.8 GW from RES (42.1 GW Hydro, 66.8 GW Solar, 42.6 GW Wind, 4.7 GW Small Hydro, 4.8 GW PSP, 10.8 GW Bio-power) (excluding 0.589 GW Diesel based Capacity). The detailed fuel-wise breakup of the total installed capacity of the country as on 31.03.2023 and energy contribution from different sources during 2022-23 is given in **Table1** and **Exhibit 5.1** respectively.

Table 1

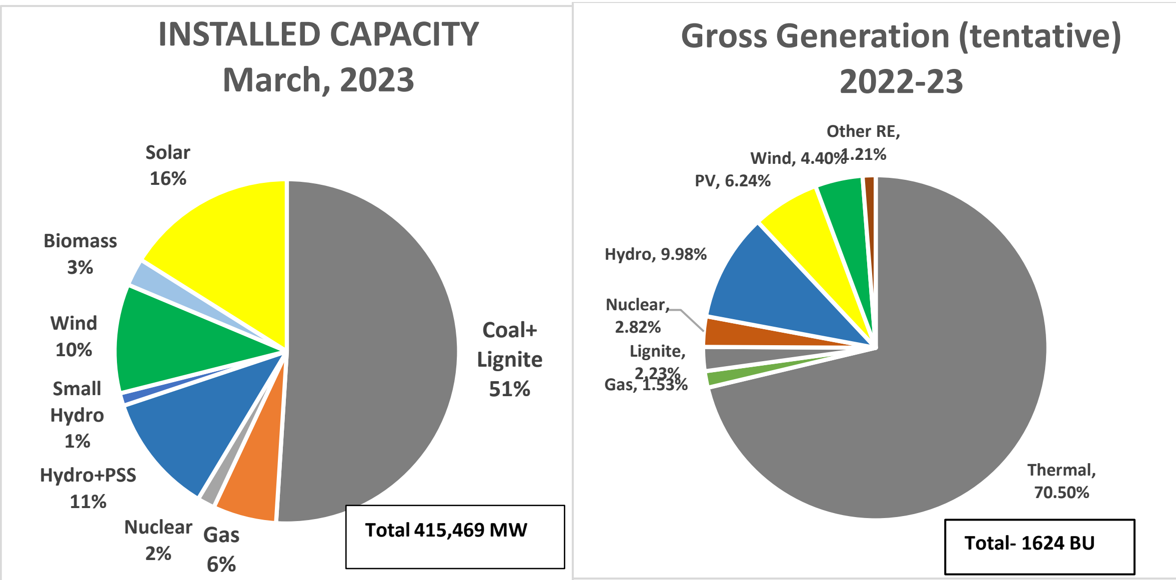
Installed Capacity as on 31.03.2023

Resource	Capacity (MW)
Hydro*	42104
PSP	4746
Small Hydro	4944
Solar PV	66780
Wind	42633
Biomass	10802
Nuclear	6780

Coal+ Lignite	211855
Gas	24824
Total Installed Capacity	**415,469**

*Excluding 2136 MW of Hydro imports from neighboring countries and 589 MW Diesel based capacity

Exhibit 5.1



It can be observed that the share of coal-based capacity is 51% in total capacity mix as on March, 2023 whereas it contributed to about 73 % of the total electricity generation of the country during 2022-23.

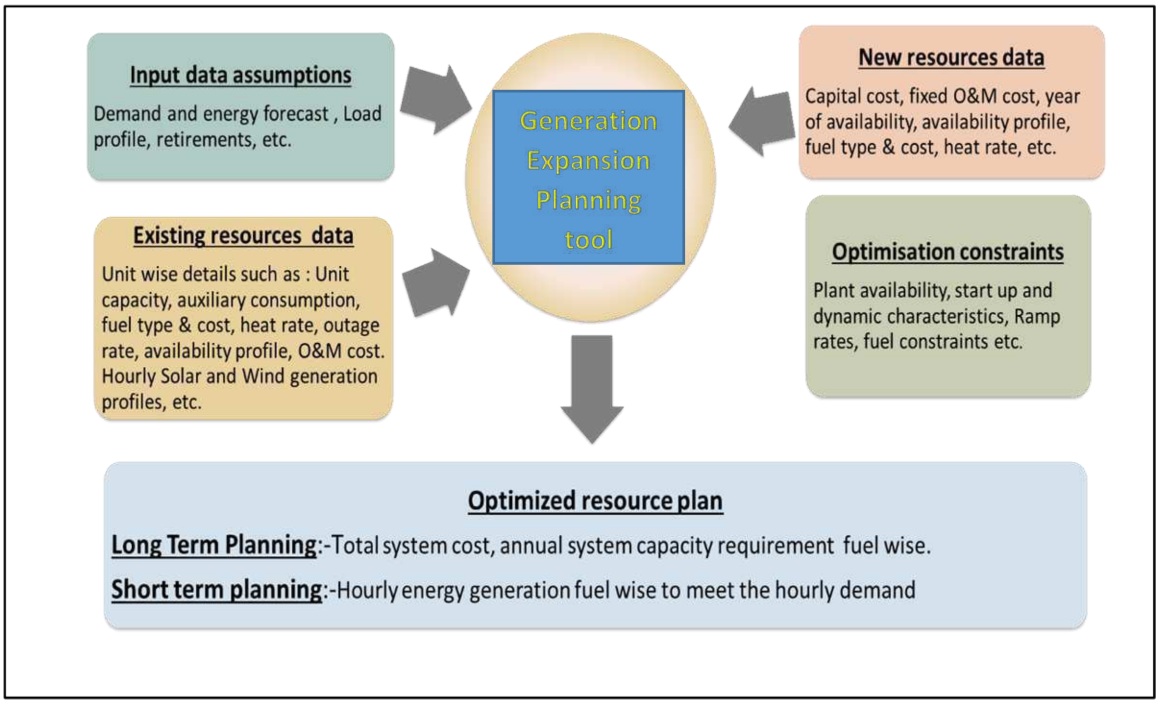
6.Generation Expansion Planning Tools

6.1 Generation Expansion Planning Tool- ORDENA

The optimal generation mix study for the year 2029-30 has been carried out using the state-of-the-art computer Generation Expansion planning model. The model performs generation expansion planning, production costing and has the capability of modelling renewable energy sources using Mixed Integer Programming. The model minimises the cost of energy generation including the capital investments required for meeting peak electricity demand and electrical energy requirement by carrying out numerous iterations for selecting the most optimal generation capacity mix considering all financial parameters and satisfying technical/operational constraints. It optimizes the cost of transportation of fuel and emissions from power plants. The software has the capability to carry 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 as **Exhibit 6.1**.

Exhibit 6.1



6.2 Generation Expansion Planning Tool- PLEXOS

PLEXOS is a powerful simulation engine that provides analytics and decision-support to modelers, generators, and market analysts. Unlike other optimization platforms, PLEXOS offers both flexible and precise simulations across several markets—electric, water, gas and renewable energy.

PLEXOS unifies the market simulations across electric, water, and gas energy systems, which helps to perform long-term planning, medium-term and short-term scheduling at once.

7 Inputs for the Study

7.1 Peak Demand and Energy requirement forecast for 2029-30

The 20th Electric Power Survey (EPS) projections for peak electricity demand and electrical energy requirement for the country have been considered for the studies. The projected region-wise and All India peak electricity demand (GW) and electrical energy requirement (BU) in the year 2029-30 are given in **Table 2**.

Table 2
Projected Electricity Demand (As per 20th EPS) for 2029-30

Region	Peak Demand (GW)	Electrical Energy Requirement (BU)
Northern	116.7	707.55
Western	107	713.08
Southern	97.4	547.4
Eastern	45.7	282.26
North-Eastern	5.8	29.35
All India	**334.8***	**2279.64**

*Summation of all regional peaks to All India peak may differ due to diversity factor

The Peak and Energy demand forecasts on the electricity grid are inclusive of impact due to factors like energy efficiency, penetration of electric vehicles, and production of green hydrogen. These projections do not include the portion of electricity demand of consumers that would be met from solar rooftops. The estimated all India solar roof top generation of 34.8 BU for the year 2029-30, has been added to the demand figures in the study to incorporate the variability associated with solar rooftop generation.

7.2 Base Capacity considered as on 31.03.2022

The installed capacity of the country, as on 31st March,22 was 398,986 MW (41,977 MW Hydro; 4,746 MW PSP; 210,700 MW Coal; 24,899 MW Gas; 6,780 MW Nuclear; 4,848 MW small Hydro; 10,682 MW Biomass; 53,996 MW solar and 40,358 MW wind) (excluding 510 MW of diesel-based capacity). This has been considered as the base capacity for the studies. The region-wise, fuel-wise details of installed capacity as on 31st March, 2022 are given in **Table 3** below.

Table 3

Base Installed Capacity (MW) as on 31.03.2022

Resource	Northern	Western	Southern	Eastern	N-Eastern	All India	Percentage of Total IC
Hydro	19576	5552	9734	5088	2027	**41977**	**10.5%**
PSP	0	1840	2006	900	0	**4746**	**1.2%**
Small Hydro	1680	646	1899	337	286	**4848**	**1.2%**
Solar PV	17791	13113	21990	931	171	**53996**	**13.5%**
Wind	4327	16742	19289	0	0	**40358**	**10.1%**
Biomass	3273	3148	3733	512	16	**10682**	**2.7%**
Nuclear	1620	1840	3320	0	0	**6780**	**1.7%**
Coal+ Lignite	45879	85586	42598	35887	750	**210700**	**52.8%**
Gas	5781	10806	6492	100	1720	**24899**	**6.2%**
Region-wise Installed Capacity#	**99927**	**139273**	**111061**	**43755**	**4970**	**398,986**	**100%**

#Excluding 2136 MW of Hydro imports from neighboring countries and 510 MW Diesel based capacity

The current installed capacity of the country, as on 31.03.2023 is 415.4 GW, which comprises of 236.68 GW from Thermal (211.8 GW Coal + Lignite & 24.8 GW Gas), 6.78 GW from Nuclear, 167.2 GW from RES (42.1 GW Hydro, 66.8 GW Solar, 42.6 GW Wind, 4.7 GW Small Hydro, 10.8 GW Bio-power) and 4.75 GW from PSP (excluding 0.589 GW Diesel based Capacity).

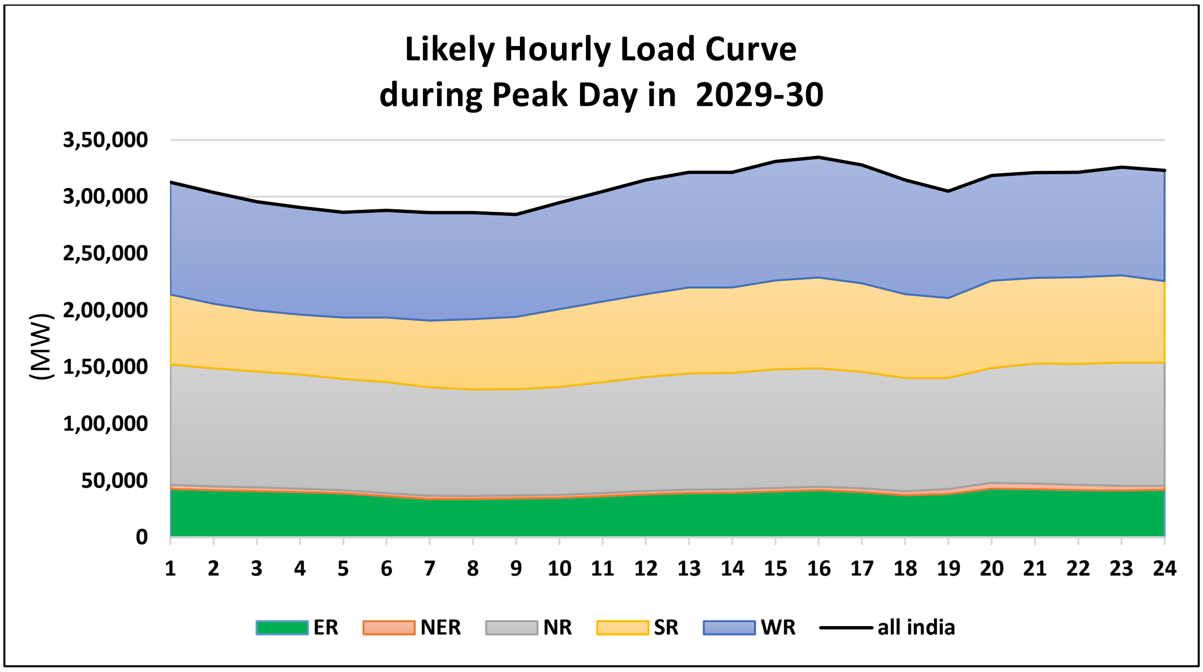
7.3 Hourly Load/Generation profile for the years 2029-30

a) Region-wise hourly Load profile

The most important aspect of any generation planning study is hourly demand projections. Hence, the endeavor has been to project the hourly demand profile meticulously, for the year 2029-30. The hourly demand profiles of the previous seven years (2015-16 to 2021-22) were examined for each of the 5 regions. The most recent hourly demand values for the years 2020-21 and 2021-22 were not considered due to the impact of Covid-19. Therefore, the hourly demand values for the years 2018-19 and 2019-20 have been considered for the studies, as they were found to be most representative of the shape of hourly demand pattern in recent times.

To obtain the likely hourly demand profile for the year 2029-30 for each of the five regions, the two years' hourly demand values viz. 2018-19 and 2019-20 has been considered, which have been normalized and subsequently extrapolated w.r.t the projected annual peak demand and electrical energy requirement for 2029-30 as per 20th EPS report. The likely hourly demand curves for the peak day in 2029-30 for each of the five regions are shown as **Exhibit 7.1**.

Exhibit 7.1



b) Region-wise hourly generation Solar and wind profiles

The actual hourly generation profile of solar and wind have been gathered from RE rich states having considerable share in the All-India VRE generation. The hourly-normalized generation profiles for solar and wind of various states of a region were then aggregated to obtain hourly-normalized generation profiles for each of the five regions.

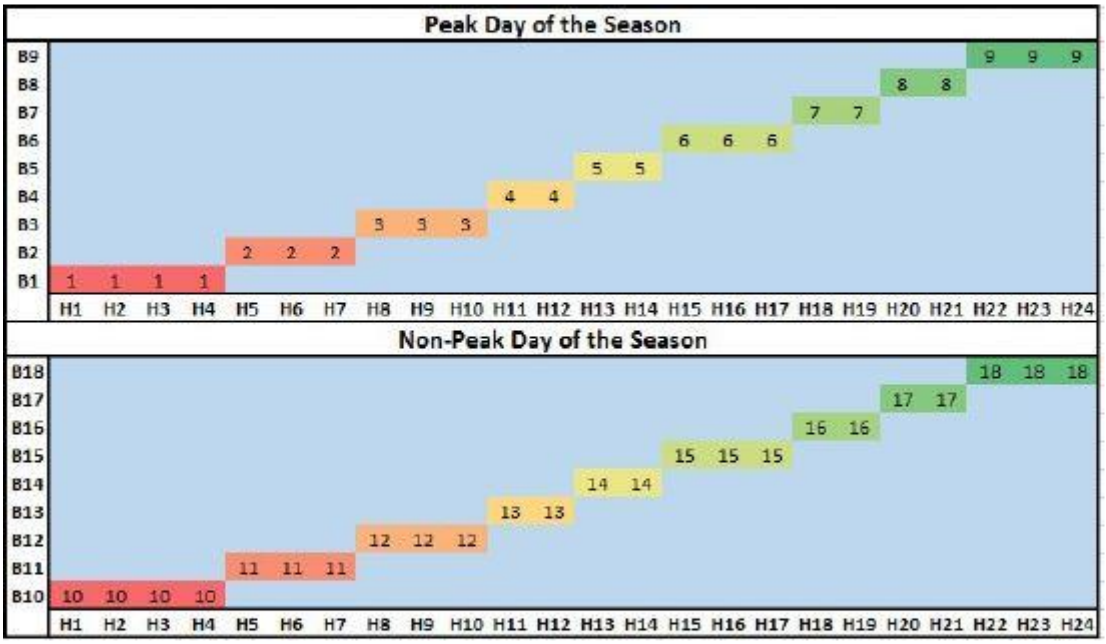
c) Creation of aggregated time Blocks for Generation Expansion Planning

The long-term models with endogenous investments are computationally demanding when optimizing investment decision as well as reducing operational cost for multiple years simultaneously. A common way to reduce computation time is to optimize the dispatch decision only for a limited number of representative time slices/blocks, instead of modelling every hour of the year. The 8760 hours is then represented by a set of time blocks or representative hours that capture changes in seasonal, weekly and daily demand pattern as well as wind and solar availability to reduce the computational burden.

Each season has been divided into blocks based on the RE generation profile for increasing the granularity and precision of the study. The annual hourly time series profiles of projected regional load, regional solar and wind generation profiles are aggregated into blocks for each of the five seasons.

The aggregation of hours of the day into time blocks in the model is shown pictorially in **Exhibit 7.2** below: -

Exhibit 7.2



7.4 Seasonal Variation of VRE and Hydro Generation

To capture the seasonal variation associated with hydro and RE generation, the time series hourly data (demand, RE generation, hydro generation) for a year has been divided into five seasons. The five seasons are as follows:

- Summer: April-June
- Monsoon: July-September
- Autumn: October-November
- Winter: December- January
- Spring: February-March

The hydro energy availability varies significantly across the years as it depends on the monsoon rains in a particular year. The actual monthly hydro generation of the existing hydro power plants for the years 2019-20 to 2021-22 have been analyzed to account for variation in generation availability due to the eventualities of drought or excess rainfall in any particular year. The monthly energy generation has been aggregated as per the format described above to arrive at the seasonal energy. The annual energy constraint of the hydro units, which are under construction or are in concurred/ S&I stage and are likely to yield benefits, have been taken based on the design energy of the project.

The model optimizes available hydro generation in such a way that maximum benefit of hydro can be exploited during peak hours along with ensuring minimum required outflow during off-peak hours. In this context, both central and state-owned hydro power plants have been assumed to contribute towards grid stability and peaking requirement of the country.

7.5 Reserve capacity

As stipulated by the National Electricity Policy 2005, 5% Spinning Reserve is to be provided. The same has been maintained while carrying out the Generation Planning studies.

7.6 Retirement of Thermal capacity

A coal-based capacity totaling to 2121.5 MW is considered for likely retirement during the study period of 2022-30. Out of this, capacity of 304 MW has retired during 2022-23.

7.7 Fuel availability constraints

Due to the unavailability of natural gas and high price of imported RLNG, fuel restriction for gas-based plants has been considered and fuel availability has been limited to present supply of the domestic natural gas (as per Domestic Gas availability during 2021-22)
Also, due to seasonal availability of Biomass, restriction on availability of fuel for Biomass based capacity (with constraint of annual PLF of around 25% to 30%) has been assumed.

7.8 Planned/under construction Capacity for likely benefits during the period 2022-30

The fuel-wise details of the projects which are under construction or in advance stages of development that are likely to yield benefit during the study period, are given in **Table 4:**

Table 4

Fuel Type	Under Construction/bid out Capacity Addition 2022-30 (MW)
HYDRO*	11494
PSP	2780
SMALL HYDRO#	502
SOLAR$	92580
WIND POWER$	25000
BIOMASS#	3818
NUCLEAR	8700
COAL	26900
GAS	0
TOTAL	**171,774**

This is assumed capacity addition for the purpose of studies.
*Excluding Hydro based Imports of 3720 MW
$ This is in line with an assumption of a planned capacity of 117.58 GW of Solar and Wind as per information furnished by SECI/MNRE.
Note: - Coal capacity of 1460 MW, Hydro capacity of 120 MW, Small Hydro capacity of 95 MW, Wind capacity of 2276 MW, Biomass capacity of 120 MW and solar capacity of 12784 MW commissioned during 2022-23.

7.9 Investment options considered for selection by model

- Coal based super critical plants at pit head locations totaling to 21,240 MW have been considered as investment options for the study period.
- Location specific hydro and PSP projects totaling to 638 MW and 11460 MW respectively, which have been concurred by CEA or are under S&I stage, have been considered as investment options for the studies till 2029-30.
- No Gas based plants have been considered as investment options for the studies.
- No additional Nuclear based plants have been considered as investment options for the studies apart from the plants which are currently under construction.
- Based on region-wise RE potential capacity data received from MNRE, region-wise PV and wind-based candidate capacity has been considered as input for the studies. The regional potential has been worked out based on state level potential furnished by MNRE.
- Region-wise BESS candidate of different sizes, i.e., 2- hour, 4-hour, 5-hour, 6-hour have been considered for the studies.

7.10 Inter-Regional Transmission Capacity

The inter-regional transmission capacity, as on 31st March, 2022, has been considered for the planning studies. The details of the same are given in **Table 5**:

Table 5

Inter-Regional Transmission (Transfer) Capacity (bi directional) in FY 2021-22

(All Figures in MW)

ER-NER	ER-WR	ER-NR	ER-SR	NER-NR	NR-WR	WR-SR	TOTAL
2,860	21,190	22,530	7,830	3,000	36,720	18,120	112,250

Additionally, candidate lines between the regions have also been considered. The capital cost of a candidate inter regional transmission links is assumed to be Rs. 10,163/MW-km and for lines to and from NER it is assumed twice.

8 Generation planning studies for the year 2029-30

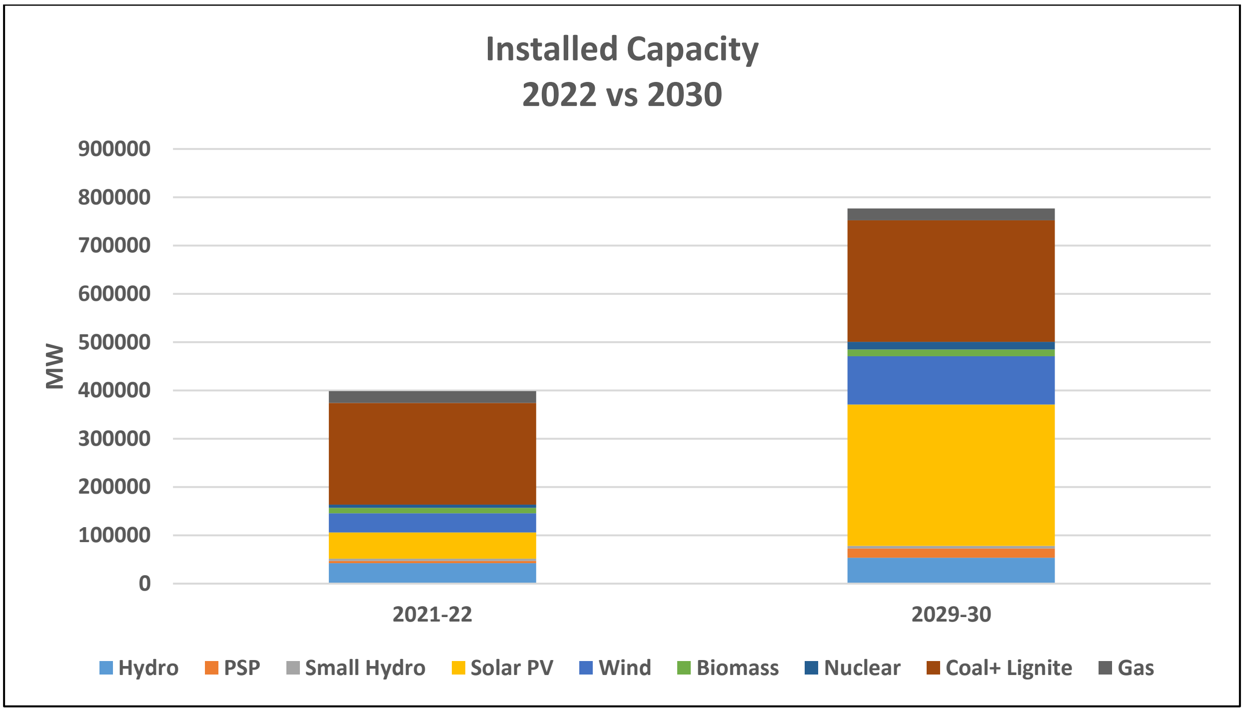
8.1 Long Term studies

Studies were carried out with the inputs/assumptions elaborated in section 7 using sophisticated computer-based generation expansion planning modelling tool to find out the least cost option for system expansion for the year 2029-30.

The model determines the least cost optimal expansion path to arrive at the optimal generation capacity mix for the year 2029-30, taking into account all the technical/financial parameters associated with various power generation and storage technologies for the study period.

The results of the generation capacity mix based on the long-term generation planning studies for the study period (2022-30) are shown in **Exhibit 8.1**.

Exhibit 8.1



Graphs are indicative and are not to the scale.

The likely installed capacity by the end of the year 2029-30 is given in **Table 6**. The region-wise details of likely installed capacity in 2029-30 is given in **Exhibit 8**.

Table 6

Likely Installed capacity (MW) in 2029-30

Resource	All India	Percentage of Total IC (%)
Hydro	53860	6.93%
Small Hydro	5350	0.69%
PSP	18986	2.44%
Solar PV	292566	37.65%
Wind	99895	12.85%
Biomass	14500	1.87%
Nuclear	15480	1.99%
Coal+ Lignite	251683	32.38%
Gas	24824	3.19%
Total#	**777144**	100%
BESS(MW/MWh)	41650/ 208250	

Excluding Hydro Imports of 5856 MW

Exhibit 8.2

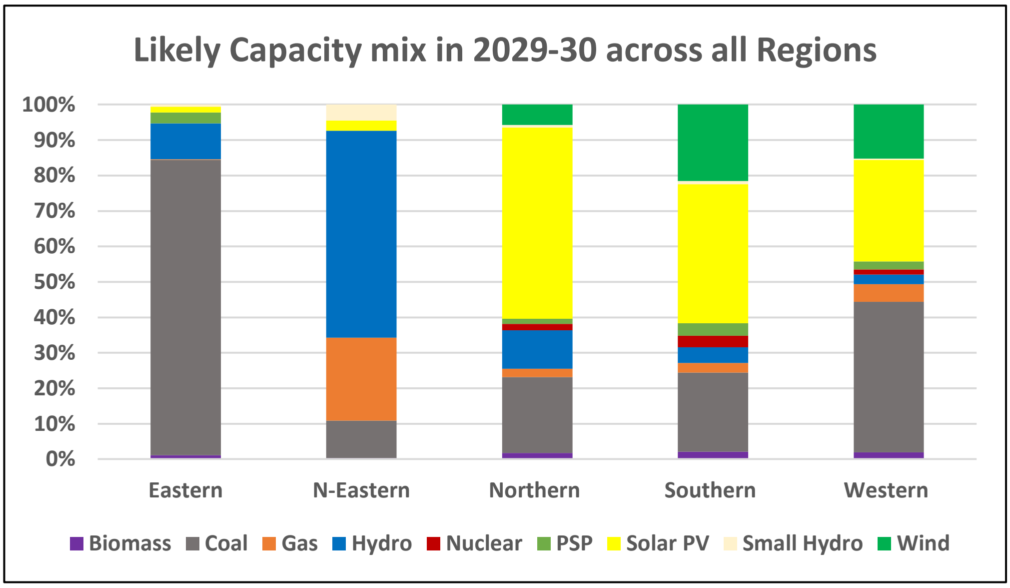
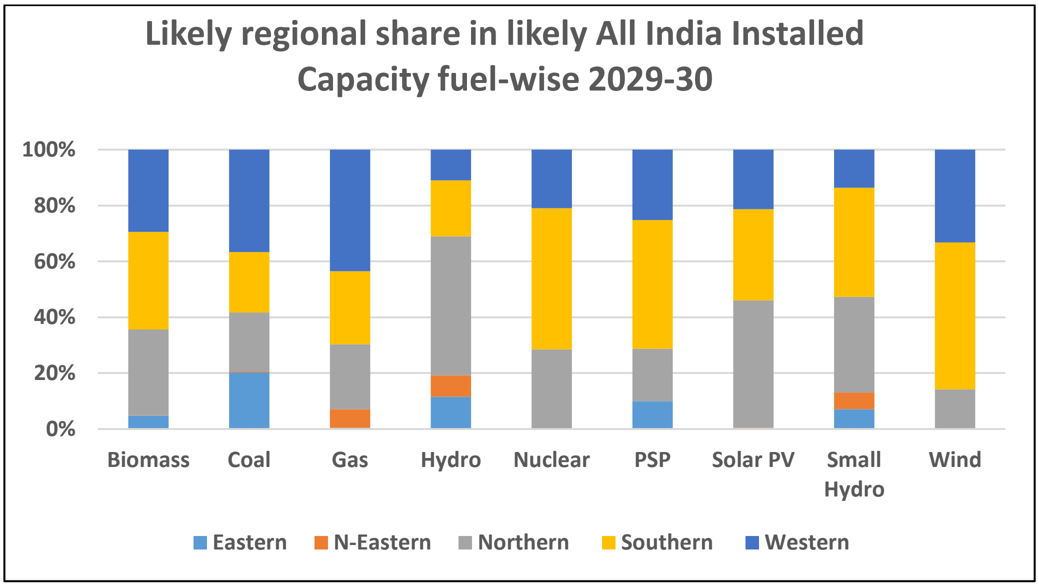
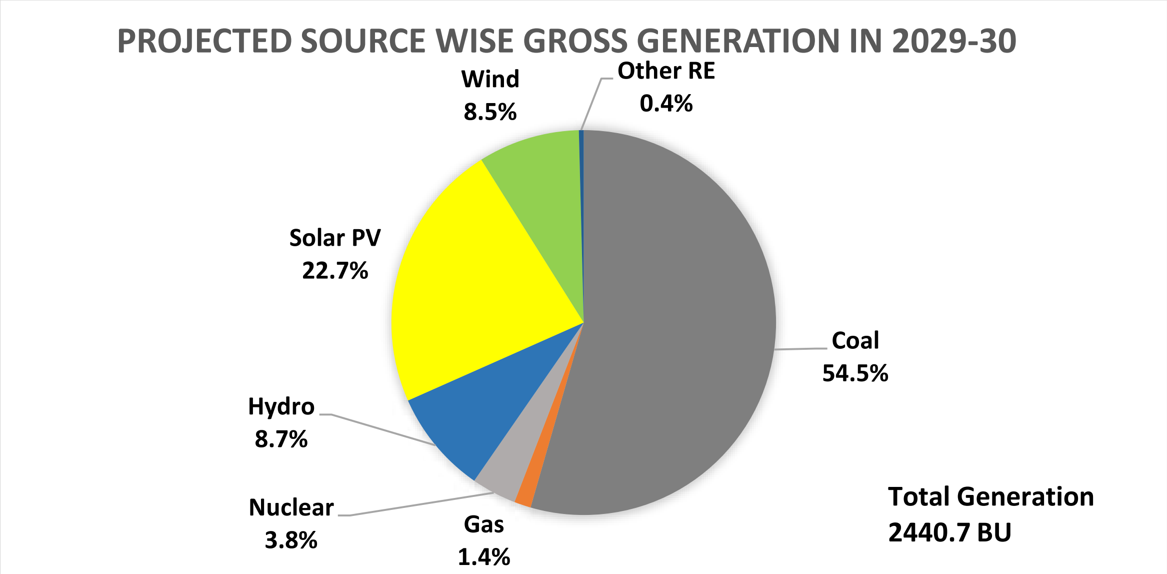


Exhibit 8.3



The region-wise estimated BESS during 2029-30 is 30.5 GW/152.5 GWh for Northern region and 11.1 GW/55.5 GWh for Southern region. The projected gross electricity generation (BU) for the year 2029-30 is likely to be 2440.7 BU comprising of 1364.5 BU from thermal (Coal, Gas and Lignite), 984 BU from RE Sources (including 222.5 BU from Hydro), and 92.2 BU from nuclear as shown in **Exhibit 8.4**.

Exhibit 8.4



* Including Generation from hydro imports.

It can be seen from the above that in the year 2029-30, Non fossil (Nuclear. solar, wind, biomass, Hydro) based installed capacity is likely to be about 64% of the total installed capacity and non-fossil fuels contribute around 45% of the gross electricity generation during the year 2029-30.

8.1.1 Inter-regional flows between the regions

The aggregate net inter-regional flows between the regions on a monthly basis is given in the **Table 7** below.

Table 7

Projected seasonal inter regional flows (BU)

	Apr'29- Jun'29 (S1-Summer)	Jul'29-Sep'29 (S2-Monsoon)	Oct'29-Nov'29 (S3-Autumn)	Dec'29-Jan'30 (S4-Winter)	Feb'30-Mar'30 (S5-Spring)
ER-NER	165	812	559	874	589
ER-NR	6693	8653	2601	10186	-937
ER-SR	762	-5935	412	1244	7471
ER-WR	-641	-3130	2773	1183	2930
NER-NR	-208	968	190	-319	-690
NR-WR	1127	-17500	4450	-1063	5248
WR-SR	0	-8940	-214	0	8665

From the above table, it is observed that, ER is likely to be energy surplus region most of the time during the year.

The quantum of the power flow from ER and WR to other regions of the country is likely to increase specifically in the low wind/ low RE months of September to December, primarily due to increased need of dispatchable coal-based power in NR and SR.

The net flow of power from ER, WR to SR is seen to decrease during June to September due to high availability of RE power in the later region.

Similarly, there is net flow of power from NER to NR regions during months of July to November, while during rest of the year, the power flows from NR to NER region.

8.1.2 Conclusions based on Long term studies

i. Coal based capacity addition of 16,204.5 MW is required to meet electricity demand requirement in 2029-30 apart from the coal-based capacity of 26900 MW currently under construction (for likely benefits during 2022-23 to 2029-30).

ii. An RE based capacity of 180.4 GW (145.9 GW Solar and 34.5 GW Wind) is required by 2030 additional to the 117 GW (92.5 GW Solar and 25 GW Wind) which is currently in planning/implementation stage.

iii. An additional capacity addition of 389 MW of large hydro capacity addition is prospectively required till 2030 apart from the capacity of 11,494 MW of Hydro projects which are currently under construction (for likely benefits during 2022-23 to 2029-30).

iv. The likely share of thermal Installed Capacity reduces to 35.5 % of the total installed capacity in 2029-30 as compared to 57 % as of March, 2023 while the RE based Installed capacity in 2029-30 (including Large Hydro) increases to 62.4% of the total installed capacity as compared to 41.4 % as of March, 2023.

v. The non-fossil fuel-based IC by the end of 2029-30 is likely to be 500.6 GW which will be about 64% of the total capacity mix.

vi. The energy storage capacity required for 2029-30 is likely to be 60.63 GW (18.98 GW PSP and 41.65 GW BESS) with storage of 336.4 GWh (128.15 GWh from PSP and 208.25 GWh from BESS).

vii. As on 31.03.2023, a PSP based capacity of 4746 MW exists in the country. PSP projects totaling to 2780 MW are under construction for likely benefits till 2030. In addition to these projects, a PSP capacity of 11,460 MW is required till 2030 to meet the electricity storage requirements of the country.

viii. It is seen that many PSP plants are likely to yield benefits by 2030 in the southern region, thereby making it a cost-effective storage alternative there and thus reducing the need of additional BESS requirement in that region.

ix. It is observed that in case of BESS resource, the model chooses to invest preferably in northern region as compared to other regions. It is due to the fact that evening peak in northern region are prominent. Therefore, BESS resource is found to be most cost effective and optimally utilized if installed locally in the northern region.

x. It is observed from the studies that the interregional flows between regions in 2030 are in accordance with the direction of flows that have been observed historically. Moreover, highest monthly flows are seen in the months of March, April from NR to WR because of cheap solar generation available in the former which helps in meeting the prominent afternoon peak load of the latter.

8.2 Hourly Dispatch Studies

Production cost models or the short-term studies help to validate results from long-term generation expansion models and complement the long-term results in overcoming their internal limitation in the time resolution.

While the long-term studies for the year 2029-30 are required to assess the optimal mix in terms of investment decisions to meet the peak electricity demand and electrical energy requirement of the system, the short-term generation dispatch studies on hourly basis are required to assess the adequacy of various capacities with the technical constraints associated with various generation technologies to meet the demand at every instant of time at the lowest possible cost.

All the operational/financial parameters and technical characteristics of the units have been considered for the hourly dispatch studies to arrive at the least cost optimum hourly generation dispatch from the projected capacity for all 365 days throughout the year 2029-30.

Based on the hourly dispatch studies, it is found that the capacity mix obtained from Long term studies, consisting of 251.6 GW of Coal and Lignite based capacity, 24.8 GW of Gas based capacity and 15.48 GW of Nuclear based capacity with 485.2 GW of RE based installed capacity (comprising of 53.9 GW of Large Hydro, 18.9 GW of PSP, 292.6 GW from PV, 99.9 GW form Wind, 14.5 GW from Biomass and 5.3 GW from SHP) along with 41.65 GW/208.25 GWh of BESS is capable of meeting India's electricity demand reliably along during the year 2029-30.

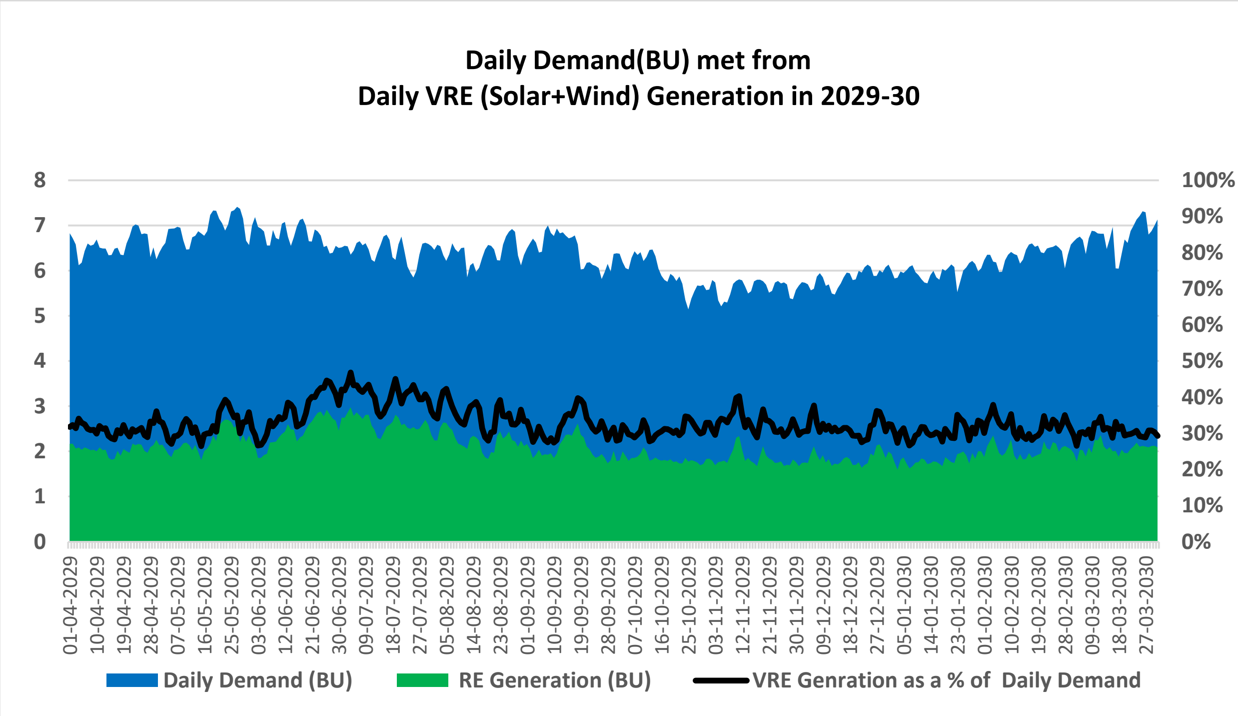
8.2.1 Analysis based on hourly dispatch for 2029-30

Following conclusions may be derived from the hourly dispatch studies for the year 2029-30 as given below:

8.2.1.1 Daily Variation in Demand and VRE Absorption

The **Exhibit 8.5** given below depicts the variation of daily demand and daily VRE generation (solar and wind only) along with the percentage of daily demand met from renewable sources (solar and wind). It may be seen that daily demand met by VRE generation is likely to vary from as high as 50% to minimum of 26% on different days of the year in 2029-30.

Exhibit 8.5

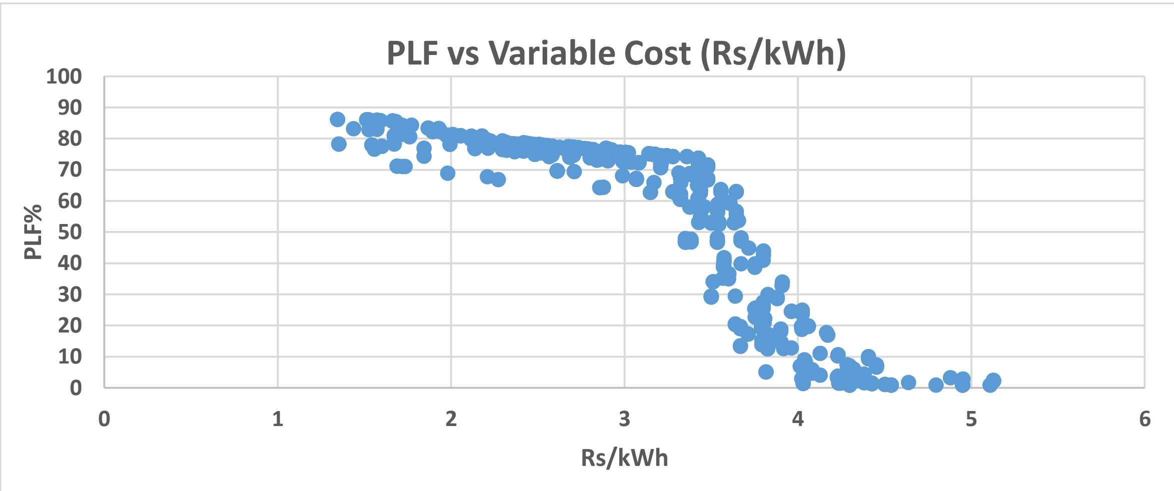


8.2.1.2 Performance Analysis of Thermal Units

A. Cost v/s PLF

The **Exhibit 8.6** below depicts the variation of PLFs of coal-based units with variable cost of generation. It may be seen from the exhibit that PLF and variable cost are inversely related. Also, majority of capacity with utilization of more than 60% have variable cost in the range of 1.3 to 3.5 Rs/kWh#.

Exhibit 8.6

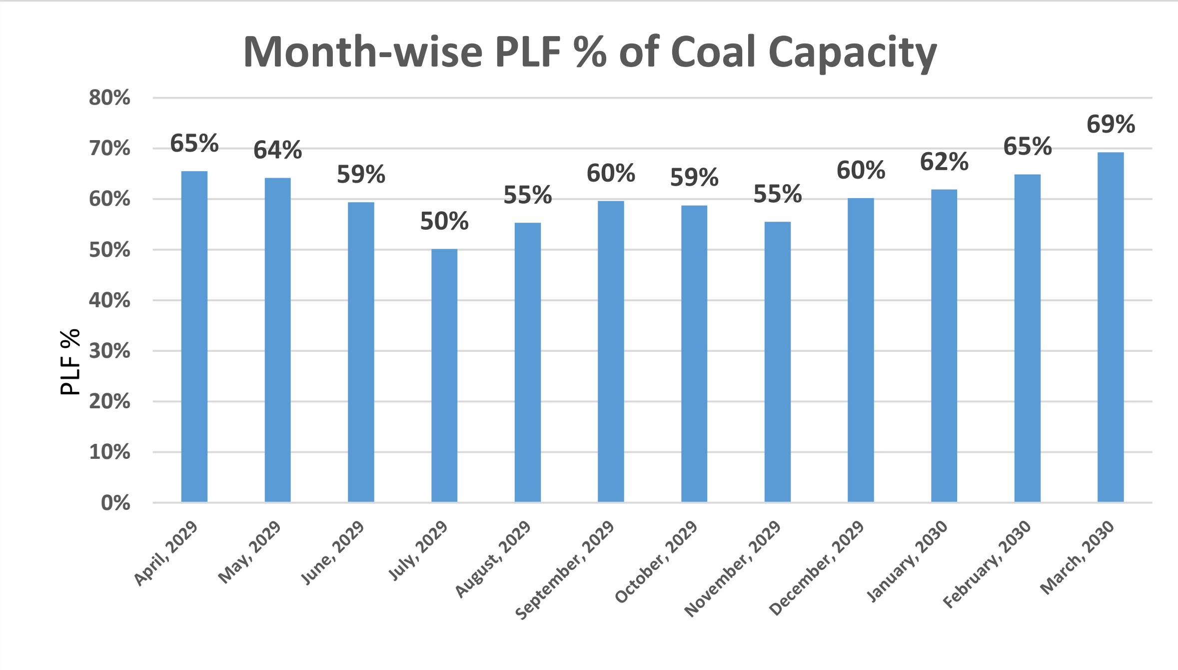


\# All Prices are at 2021-22 Level

B. Month-wise PLFs of coal capacity

Month-wise PLF of coal capacity has been analyzed and is shown in the **Exhibit 8.7** below.

Exhibit 8.7

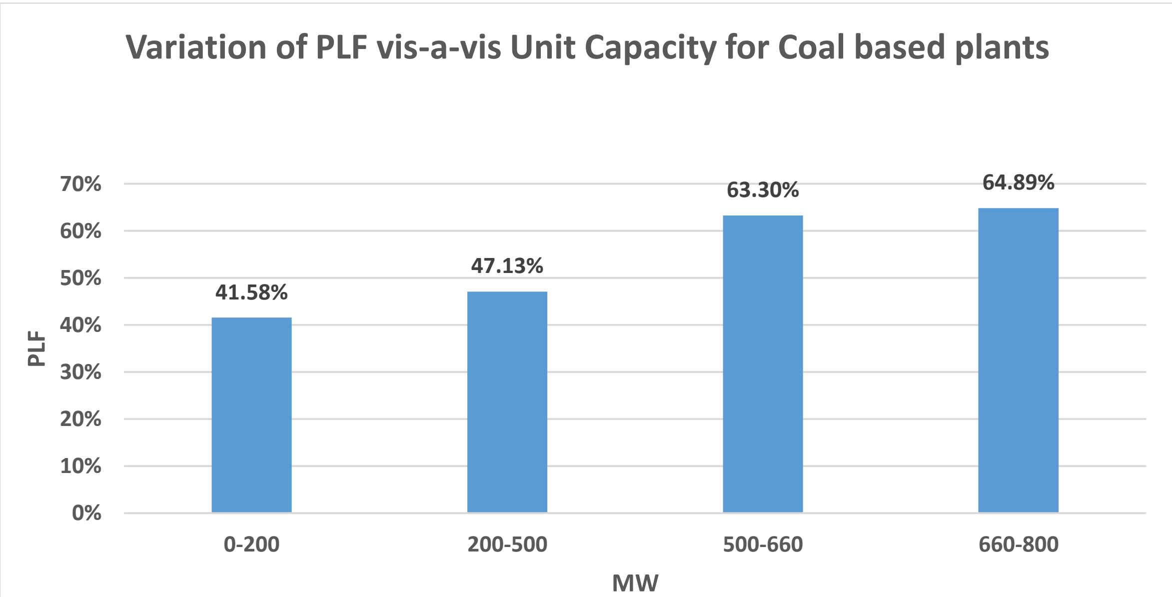


The chart shown above indicates that the lowest PLF of coal plants is expected to be in the monsoon season when Hydro and Wind Generation increases significantly and the demand is also lower historically compared to other seasons. Coal generators can optimally schedule their annual maintenance during this season.

C. Unit-wise PLF variation

The **Exhibit 8.8** shown below, depicts the variation in the PLFs of coal based units of different sizes.

Exhibit 8.8

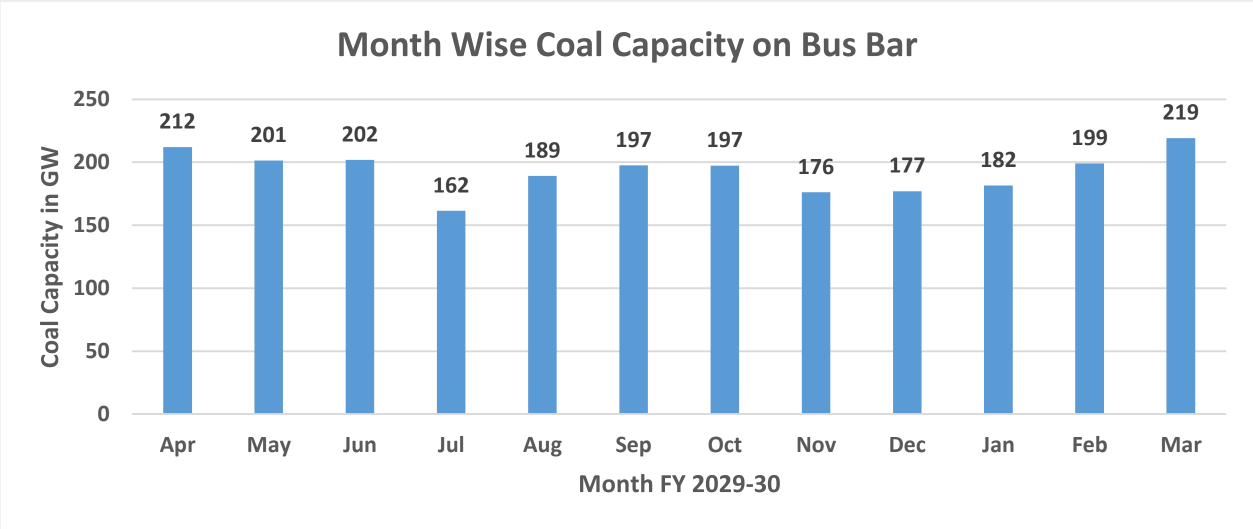


From the graph, it can be seen that the super critical and ultra-super critical plants may run at higher PLFs as compared to smaller sized less efficient units.

D. Coal capacity required on Bar

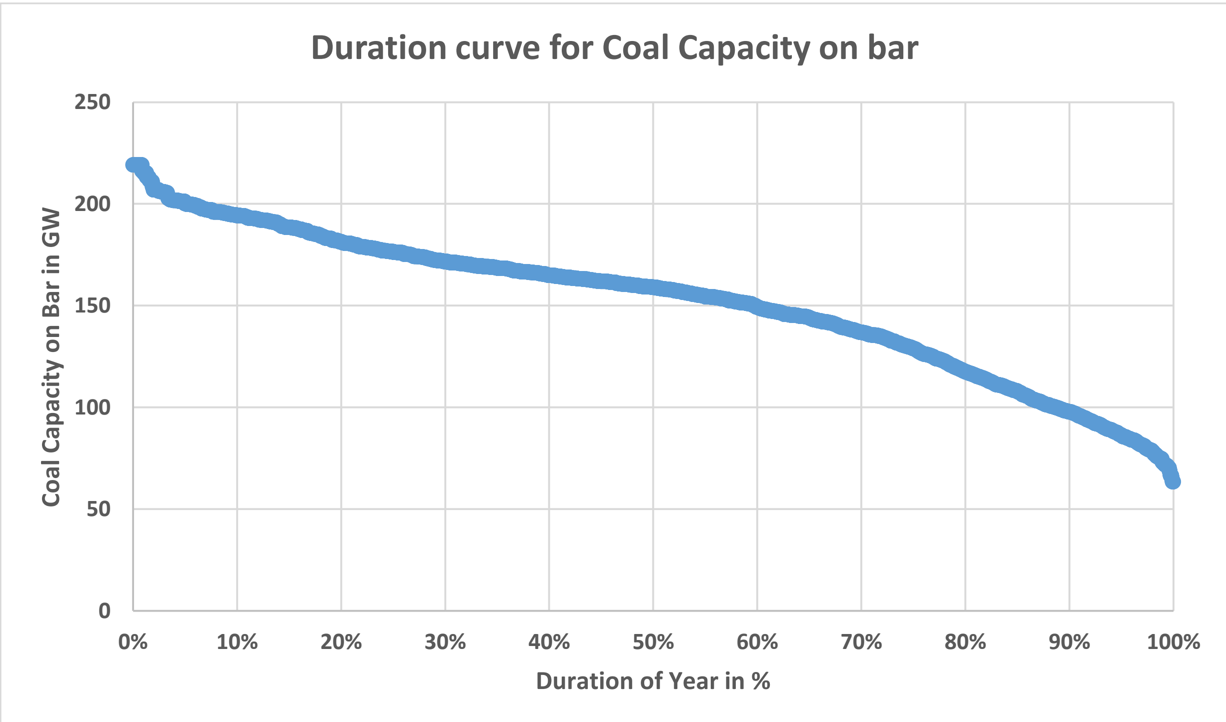
The **Exhibit 8.9** given below depicts the minimum Gross coal capacity required on bar to ensure capacity adequacy for meeting energy and peak requirement during the month.

Exhibit 8.9



It can be seen from the **Exhibit 8.10** that more than 160GW of coal based capacity is required to be on bar for more than 50% of the time for the whole year.

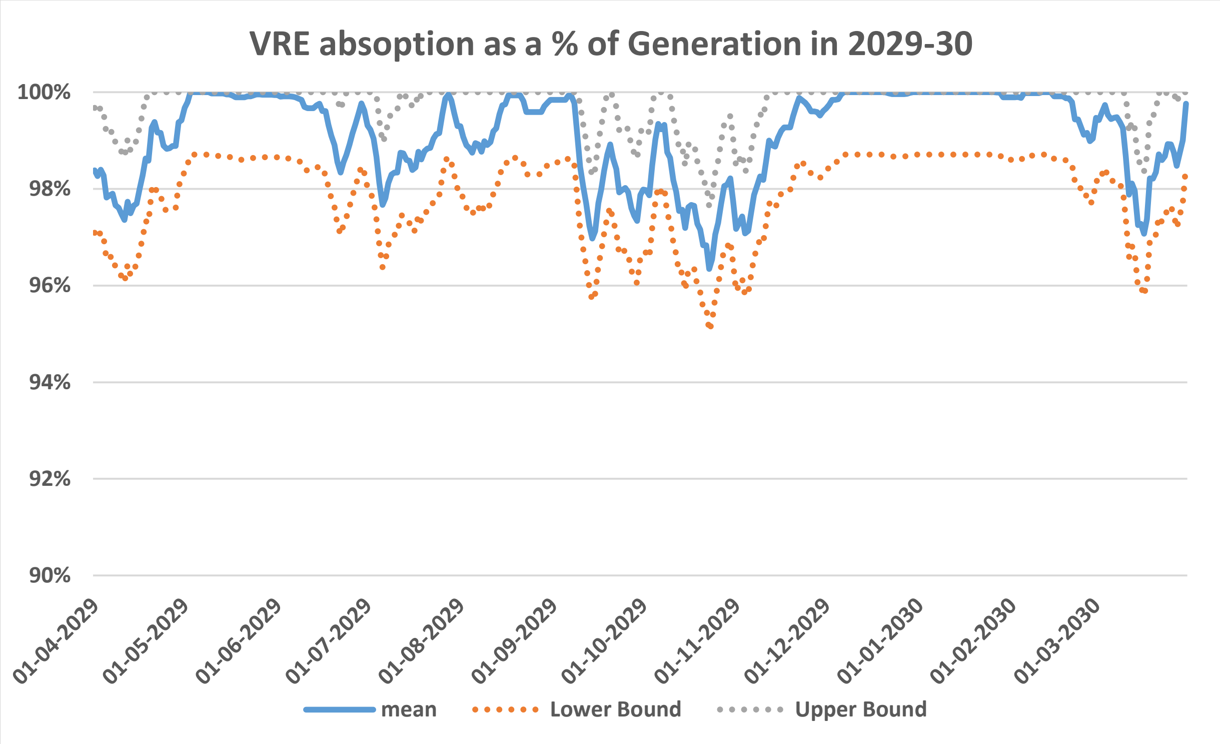
Exhibit 8.10



8.2.1.3 Projected Daily RE absorption

The **exhibit 8.11** given below depicts the trend of projected VRE absorption for each day in 2029-30.

Exhibit 8.11



Based on the studies, it can be seen that the RE absorption is likely to decrease to as low as 96% on some days during 2029-30. This is seen to occur during high solar months/ high RE months. This is due to flexibility constraints of conventional generators (typically constraint of 55% of Minimum Power Load for coal based capacity) as well as due to the load shape. Further, additional BESS to absorb this power may not be economical.

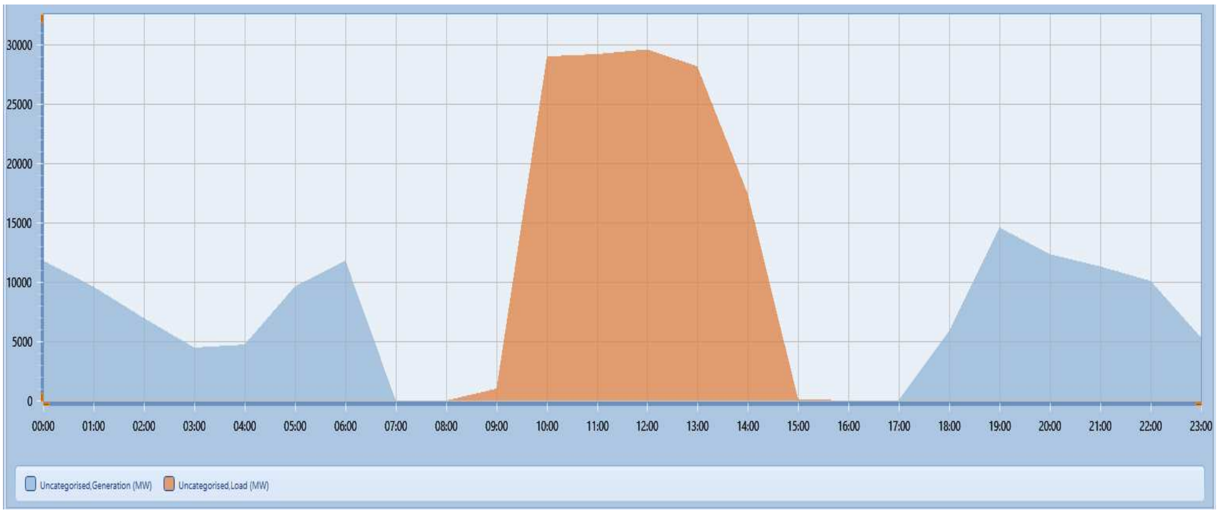
It is seen that decreasing the Minimum Power Load(MPL) of the coal based plants, the % RE absorption may increase. Additionally, if peak demand shifts in afternoon hours from evening hours then the absorption of RE will increase.

8.2.1.4 Operation of a storage resource (BESS /PSP) on a typical day

In view of large amount of Variable RE based generation likely to be integrated in the grid in the future, energy storage technology is found to be useful in maintaining grid stability and reliability by storing excess generation over different time horizons (minutes, days, weeks) and meeting the peak demand which is not coincidental with the peak RE generation.

The **Exhibit 8.12** given below depicts the hourly operation of BESS (charging and discharging behavior) on a typical day in 2029-30.

Exhibit 8.12



From the exhibit above, it can be seen that , the Storage capacities (BESS and PSP) is seen to get charged primarily during the solar hours and is used to meet peak demand as well as demand in late night and early morning hours.

8.2.1.5 Additional Observations based on hourly dispatch studies

Some of the additional outcomes of the hourly dispatch studies are as follows:

- The share of thermal generation in the total generation mix of the country is likely to reduce to 55.9 % in 2029-30 as compared to around 75% in 2022-23.
- The likely non-fossil fuel based capacity of 500.6 GW by the end of 2029-30 is likely to contribute around 44% in the total generation mix.
- The likely PLF of the coal based capacity is found to marginally increase from 59% in 2021-22 to be around 60.3 % in 2029-30.
- Energy storage technologies like PSP and BESS help in diurnal grid balancing during high RE months. Storage technologies charge during the daytime (coincident with solar generation) and discharge during the morning and evening peak periods (4-6 hours total each day). They also help to meet steep system ramping requirement. It is observed that one cycle per day operation for battery storage system is sufficient to cater to demand and generation variations.
- It has been observed that RE based generation which may not be absorbed during the year 2029-30 is likely to be around 0.78%. It decreases to 0.25% at 40% Minimum Power Load.

8.2.1.6 Reliability modelling outcomes

Monte Carlo /Stochastic simulation is an approach 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 analyzing the randomness associated with RE energy resource, demand pattern change 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.

The model has been simulated to calculate Unserved Energy (ENS) and LOLP (Loss of Load Probability) for each sample. It is observed that the system reliability indices are well within the stipulated range (i.e. 0.5% of ENS & 0.02% of LOLP).

8.2.2 Analysis of few critical days during 2029-30

The hourly dispatch studies have been carried out for all the 365 days of the year 2029-30. However, a few critical days were identified based on the generation profile of VRE resources i.e., Wind, solar and on the hourly Demand profiles. The same are elaborated in detail in this section as representative days. These are the days where the system may be stressed.

The Resource-wise generation patterns for the country (while honoring the inter-regional transmission constraints) were studied to identify the critical days with the purpose of ascertaining if the power system with the given capacity mix in the year 2029-30 is stable and resilient to meet the projected system demand at every instance of time.

The few typical days identified are given in **Table 8**.

Table 8

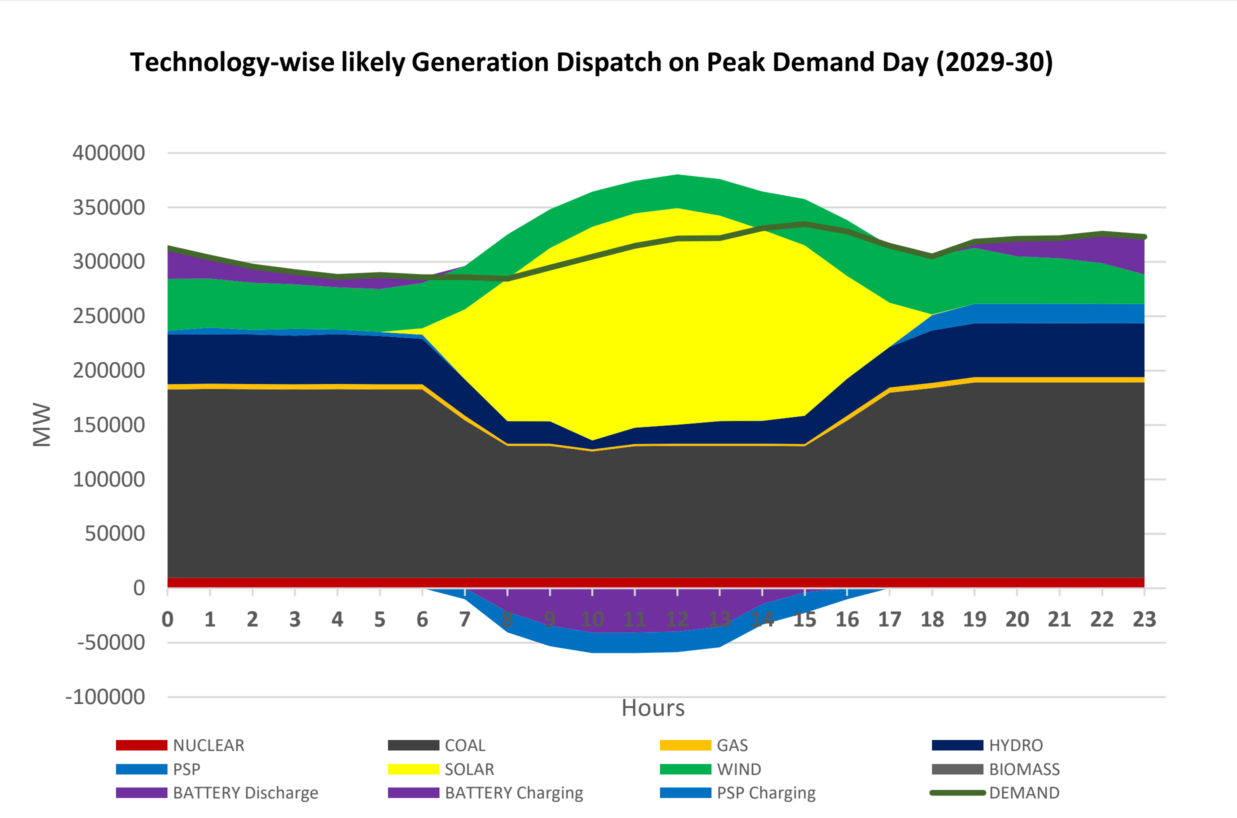
Critical Days identified during the year 2029-30

Sl. No.	Characteristic Day	Month
1	Peak Demand Day	May-June
2	Maximum VRE (Wind+ Solar) generation day	July
3	Maximum Solar generation day	March
4	Minimum Solar generation day	July
5	Maximum Energy Demand Day	May
5	Minimum Energy demand day	October-November
6	Minimum VRE (Wind+ Solar) generation day	January

8.2.2.1 Peak Demand Day – May, 2029

One of the most critical days from power planning perspective is annual peak day and it has to be ensured that there will be adequate supply for meeting the peak demand whenever it occurs. From the likely hourly demand profiles of 2029-30, it has been observed that the peak energy demand (in an Hour) may occur in the month of May-June.

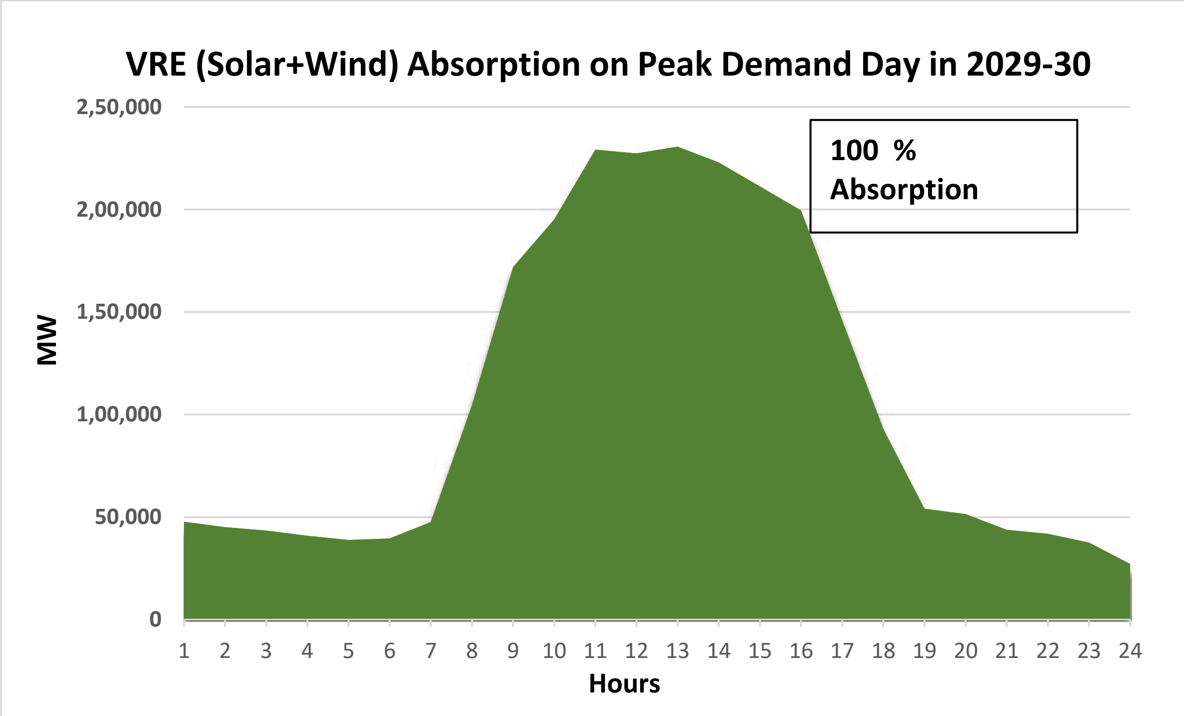
Exhibit 8.13



It has been observed that on this day when the peak demand occurs, the peak and energy electricity demand is likely to be fully met with the generation capacity mix obtained from the long-term studies. Further, it is seen that online coal capacity is running at 55% Minimum Power Load (MPL) during the hours when full solar generation is available. The battery is getting charged during the period when excess solar generation is available and dispatched during non-solar hours. RE generation is seen to be almost fully absorbed during this day. The likely solar and wind CUF is 22.97% and 40.8% respectively while the gross PLF of the coal-based capacity is likely to be 65.90% on this day. The gross coal capacity on bar on this day is likely to be 192 GW.

RE generation dispatch and absorption is shown in the **Exhibit 8.14**. The RE absorption on the peak day is likely to be 100%.

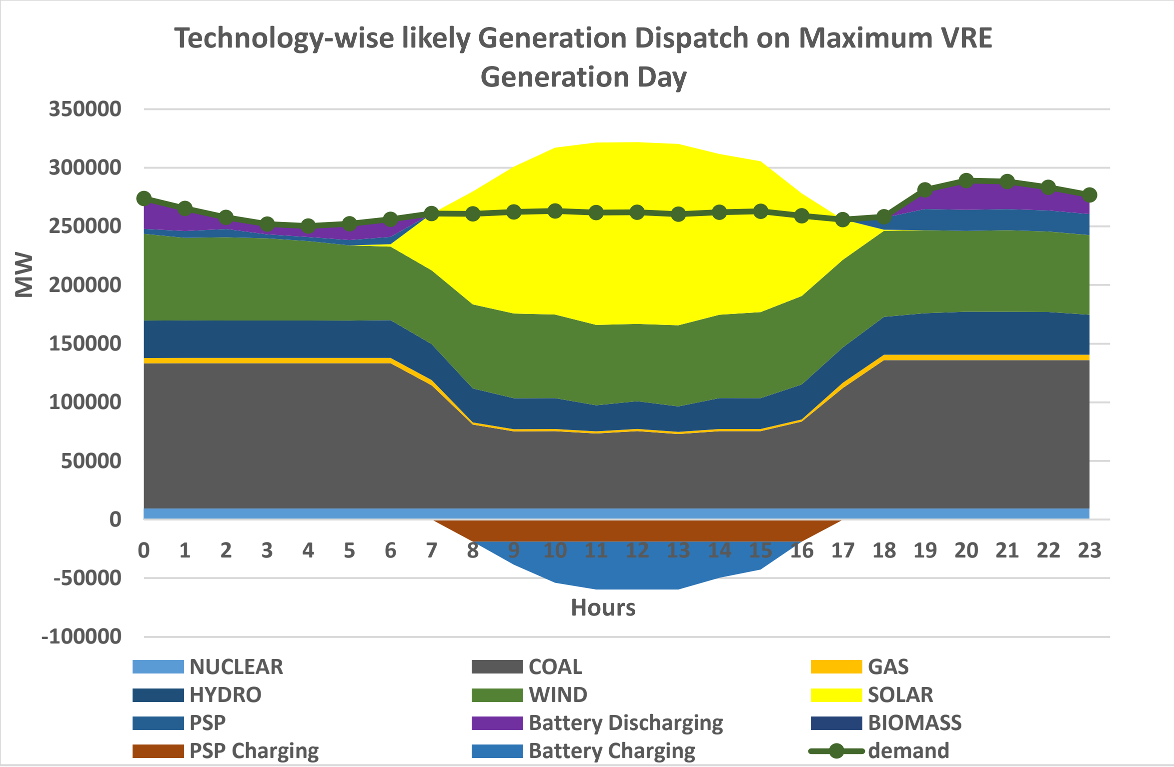
Exhibit 8.14



8.2.2.2 Maximum VRE (Wind + Solar) Generation Day – July, 2029

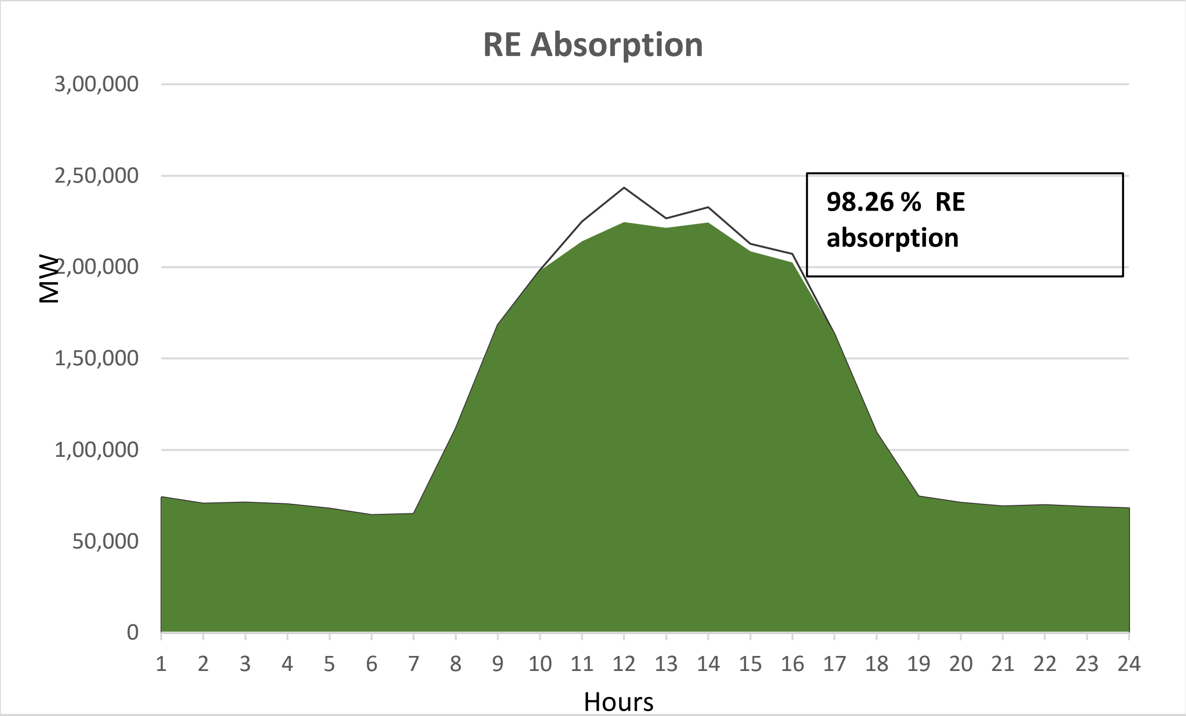
The system has to be resilient on the day when the maximum generation from RE (wind + solar) is likely to be available. The maximum generation from RE is likely to occur in the month of July. The CUF of the wind capacity is likely to be maximum (i.e., 70.06 %) on this day. The hydro generation is also maximum during the month of July. The solar CUF is likely to be only around 18.1% on this day. Hourly generation dispatch for the maximum RE generation day is shown in the **Exhibit 8.15**.

Exhibit 8.15



It has been observed that on this day during which VRE generation is maximum, the demand is likely to be fully met with the generation capacity mix obtained from the long-term studies. However, the RE absorption on this day is likely to be around 98.2%. This absorption may further increase with technical minimum load of coal-based plants reduces to 40%. RE generation dispatch and absorption is shown in the **Exhibit 8.16**. Due to higher availability of hydro and wind generation during high RE months, the annual maintenance of the coal plants may be taken up during this period. The gross coal capacity on bar during this day is likely to be 135.5 GW.

Exhibit 8.16



8.3 Scenario Analysis

Scenario analysis provides a structured way to guide strategic decision making by exploring the different possible impacts of a range of events. It explores a range of potential outcomes from best- to worst-case scenarios.

A range of different scenarios have been studied for the year 2029-30 wherein the impact of factors like increase in projected demand, delay in commissioning of capacities of different technologies have been accounted for. Additionally, a conservative scenario has been envisaged in which the possibility of deferment in the commissioning of capacity from different fuel sources which is currently under construction, based on historical trends of construction time for different technologies has been considered.

The various scenarios considered are detailed below:

1. **Conservative Scenario (Based on historical trend of capacity addition)**
2. **Higher demand scenario (5% increase in Peak and Energy demand).**
3. **Higher Hydro Scenario (accelerated Hydro and PSP addition).**
4. **Higher BESS Cost Scenario**

These scenarios and the resultant likely Installed Capacity have been outlined in detail below:

8.3.1 Scenario 1- Conservative Scenario (Based on historical trend of capacity addition)

In this scenario, the upcoming capacity addition (both capacity under construction and candidate capacity) from different fuel sources likely to yield benefit during 2022-2030 is deferred based on historical trends of construction time for different technologies as given below:

- **Coal** - 20% of the capacity addition (both under construction and candidate) have been slipped to next year.
- **Hydro (incl. PSP)-**Under construction plants have been delayed by 2 or 3 years based on progress of work of plant. Plants in concurred/S&I stage have been delayed by 2 years
- **Nuclear**- Capacity under construction delayed considering 12 years of construction time from the year the construction started.
- **Solar and Wind**- Delayed capacity addition of solar and wind projects when compared to base case.

The likely installed capacity for the year 2029-30 is given in **Table 9**.
It is seen in this scenario that the coal based installed capacity in 2029-30 decreases to 248.43 GW from 251.6 GW in base case scenario (This is due to delayed capacity addition assumed for coal-based capacity in pipeline). The BESS storage capacity requirement increases by 4 GW/20.3 GWh in this scenario compared to base case.

8.3.2 SCENARIO 2- High demand scenario (5% increase in Peak and Energy demand).

In this scenario an increase of 5% in both the estimated peak demand as well as energy Requirement for the year 2029-30 has been considered. The likely installed capacity in this scenario is given in **Table 9**.
It can be seen that increase in electrical demand by 5% in 2029-30, entails an increase in capacity addition requirement from coal to 254.6 GW from 251.6 GW in base case and an increase in storage capacity of BESS by 7.7 GW/38.6 GWh when compared to base case.

8.3.3 SCENARIO 3- High Hydro Scenario (accelerated Hydro and PSP addition).

This scenario assumes that the capacity addition from hydro and PSP based projects, which are in pipeline (under construction/concurred/S&I) during the period of 2023-30, are accelerated by 2/3 years each so that they may yield benefit earlier than envisaged in the base case.

It is seen in this scenario that BESS storage capacity decreases by 19.037 GW/95.2 GWh compared to base case.

8.3.4 SCENARIO 4- Higher BESS cost scenario

In view of the volatility of commodity prices, a scenario has been studied, wherein the cost of BESS is considered to increase by 25% as envisaged in base case.

It is seen in this scenario that storage capacity of BESS decreases by 8.2 GW/41.5 GWh compared to base case while coal capacity increases by 1.6 GW (251.6GW in base case -> 253.3 GW).

Results of different scenarios have been summarized in the **Table 9** below.

Table 9

Likely Installed Capacity by end of 2029-30 in different scenarios

(All figures in MW)

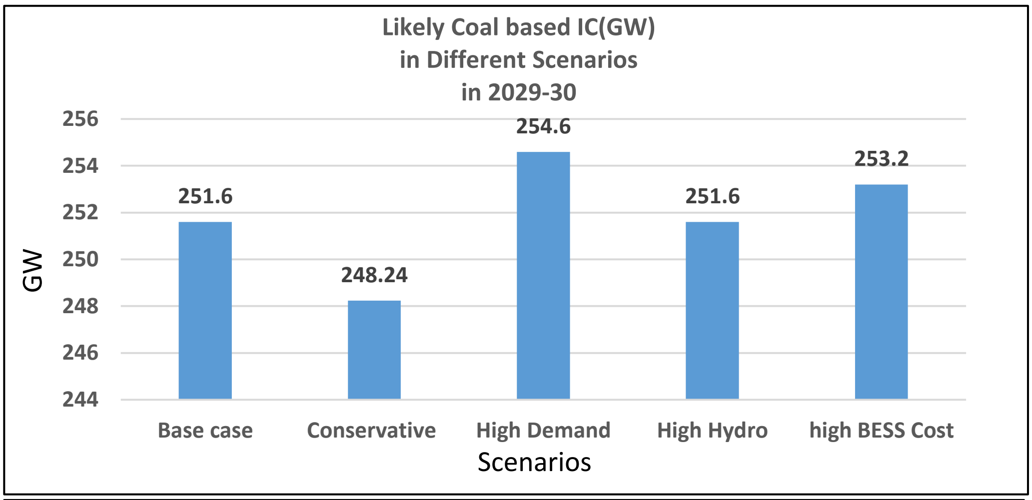
Scenario	Base Case	Conservative Scenario	High Demand (5%)	High Hydro	Higher BESS Cost
Hydro *	53860	53860	53945	62434	53945
PSP	18986	17256	18986	24736	18986
Small Hydro	5350	5350	5350	5350	5350
Coal+Lignite	251683	248243	254603	251683	253283
Gas	24824	24824	24824	24824	24824
Nuclear	15480	12080	15480	15480	15480
Solar	292566	270566	292566	292566	292566
Wind	99895	75396	99895	99895	99895
Biomass	14500	14500	14500	14500	14500
Total	**777144**	**722128**	**780202**	**791468**	**778829**
Fossil IC	**276507**	**273067**	**279427**	**276507**	**278107**
Non-Fossil IC	**500637**	**449061**	**500775**	**514961**	**500722**
Battery Energy Storage System (MW/MWh)	41650/ 208248	45703/ 228515	49377/ 246885	22613/ 113065	33356/ 166780

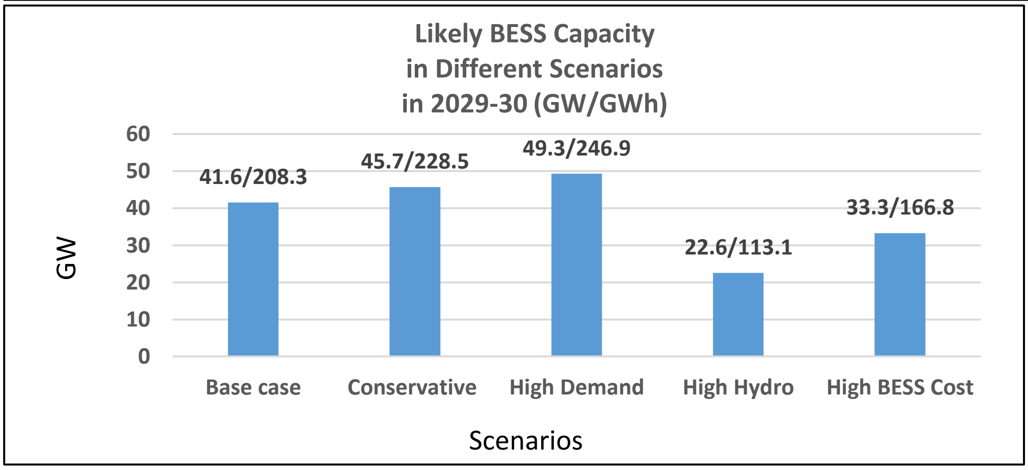
*Excl. Hydro imports from neighboring countries

Observations based on Scenario Analysis

- The likely coal based and BESS installed capacity by end of 2029-30 in different scenarios is shown in **Exhibit 8.17** below.

Exhibit 8.17





- It is observed that the range of coal capacity required in the year 2029-30 varies from 248.3 GW in Conservative Scenario to around 254.6 GW in high demand scenario.
- From scenario analysis it is seen that apart from under construction coal-based capacity of 26.9 GW, the additional coal-based capacity required till 2030 may vary from 12.7 GW to around 19.1 GW.
- BESS requirement in 2030 is varying from 22.6 GW/113.1 GWh to 49.3 GW/246.9 GWh across various scenarios.
- With increase in peak demand and energy requirement, both the coal-based capacity and storage requirement (PSS and BESS) increases along with marginal increase in Hydro based capacity.

9. International Climate Commitments

In October 2015, India had submitted its Intended Nationally Determined Contribution (INDC) to UNFCCC as per which a target of achieving 40 percent of cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 was envisaged. India has already achieved the share of non-fossil fuel-based capacity of 40% in total

Installed capacity mix as on 31.03.2022. Moreover, the target of reducing the emissions intensity of its GDP by 33% to 35 % by 2030 from 2005 level will be fully met much before the year 2030.

As per the updated NDC being submitted to UNFCCC in 2022, India now stands committed to reduce Emissions Intensity of its GDP by 45 percent by 2030, from 2005 level and achieve 50 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030.

In March 2022, percentage of non- fossil fuel in installed capacity was 41 %. Studies for the year 2029-30 show that it is likely to increase to around 64% in March 2030. **Table 10** give the percentage of non-fossil installed capacity by the end of 2029-30.

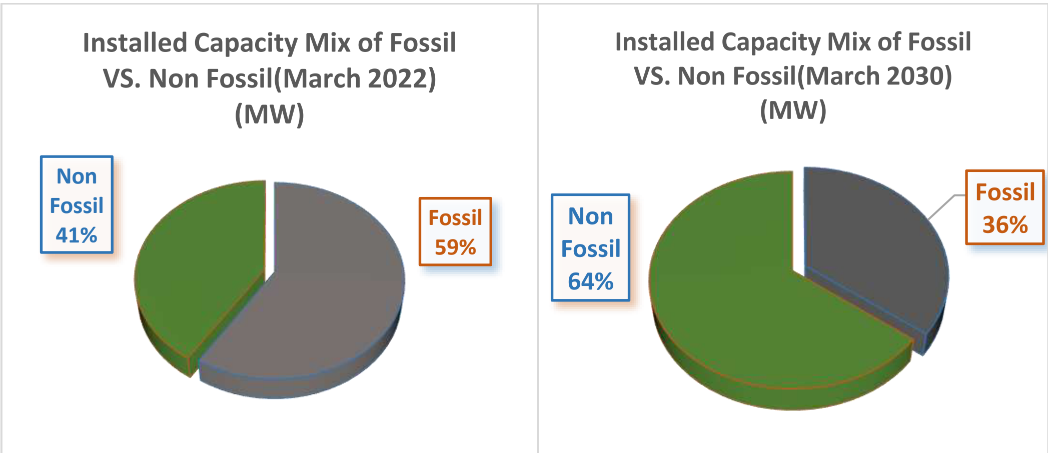
Table 10

Likely Installed Capacity mix of Fossil and Non-fossil* fuels

Year	Installed Capacity (MW)	Installed Capacity of Fossil fuel (MW)	Installed Capacity of Non-Fossil fuel (MW)	%Of Non-fossil fuel in Installed Capacity
March,2022	398,986	235,598	165,523	41%
March,2030	777,144	276,507	500,637	64.4%

* Non-Fossil Fuel – Hydro (including imports), Nuclear and Renewable Energy Sources

Exhibit 9.1



10. CO_2 emissions from Power Sector by 2030

As per studies, the CO_2 emissions from the power sector during the year 2029-30 is likely to be 1114 MT as shown below in **Table 11**.

Table 11
Annual CO_2 Emissions

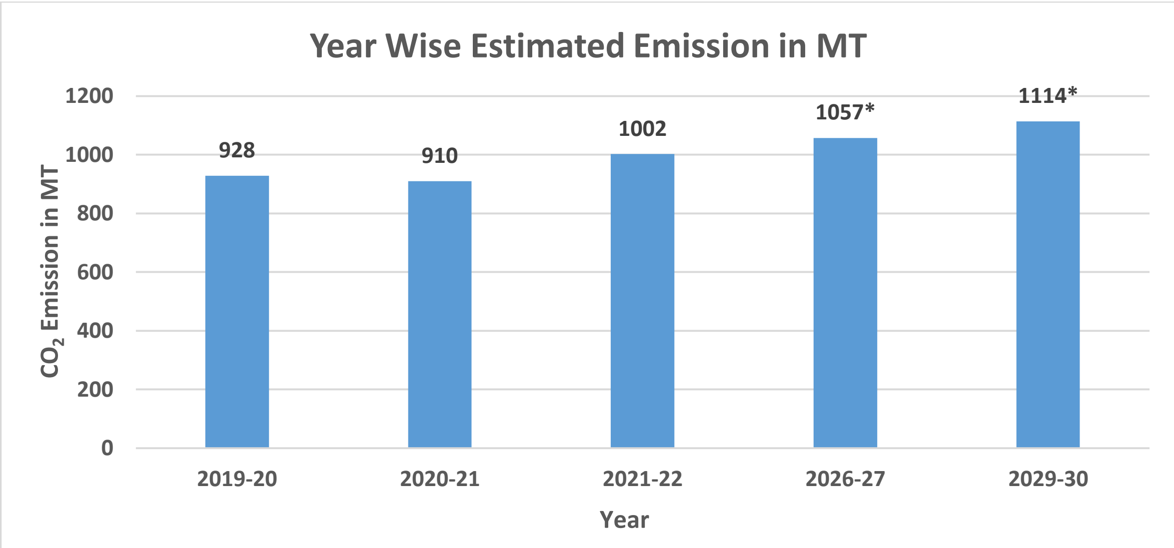
	Year 2020-21#	Year 2021-22#	Year 2029-30
CO_2 Emissions Million Tonnes	910	1002	1114*

#Actual value as per CO2 baseline database of CEA
*Projected CO2 emissions

Note: Actual CO2 emissions may vary depending on the actual RE generation

The total CO_2 emissions has increased from 910 million tonnes in the year 2020-21 to 1002 million tonnes in the year 2021-22. As per the studies, CO_2 Emissions from power sector are likely to increase to 1114 million tonnes in the year 2029-30 as shown in **Exhibit 10.1**.

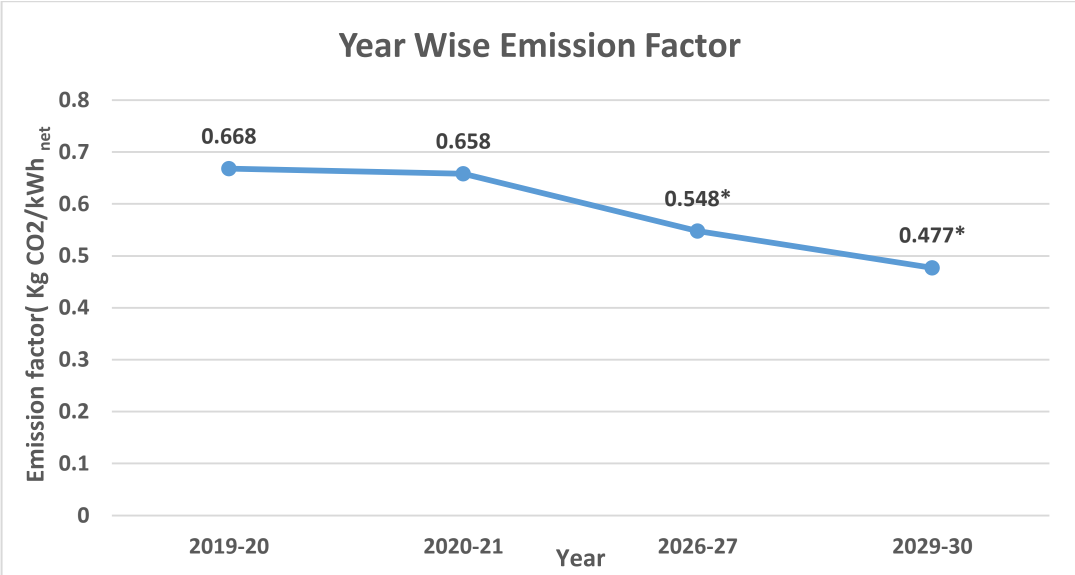
Exhibit 10.1



*Projected Emissions

The average emission factor $kgCO_2/kWh_{net}$ from the total generation including renewable energy sources in base case scenario has been estimated and is shown in **Exhibit 10.2**. The average emission factor is likely to reduce to 0.477 $kgCO_2/kWh_{net}$ by the year 2029-30.

Exhibit 10.2



*Projected Emission factor

11.Projected Coal Requirement in 2029-30

The Gross Generation from coal and lignite-based power plant is estimated to be 1515.82 BU for the year 2029-30. The estimate includes likely increase in coal-based generation on account of the uncertainty in realization of the expected/scheduled capacity addition from Hydro, Nuclear, VRE sources and/or climactic factors like drought conditions, etc.

The resultant coal requirement for the year 2029-30 has been worked out to be about 1019.6 million Tonnes considering specific coal consumption of 0.666 kg/kWh + 1% transportation loss.

12.0 Conclusions

- The projected All India peak electricity demand and electrical energy requirement is 334.8 GW and 2279.7 BU for the year 2029-30 as per the draft 20th EPS projections.
- The installed capacity by the end of 2029-30 projected is 777,144 MW comprising of Hydro 53,860 MW (excluding Hydro Imports 5,856 MW), PSP 18,986 MW, Small Hydro 5,350 MW, Coal 2,51,683 MW, Gas 24,824 MW, Nuclear 15,480 MW, Solar 2,92,566 MW, Wind 99,895 MW and Biomass 14,500 MW along with a Battery Energy Storage capacity of 41,650 MW/208,250 MWh. With this installed capacity, the NDC commitment given by India i.e., the percentage of non- fossil fuel capacity in the total installed capacity is to be 50% by 2030 is likely to be met.

- The energy storage capacity required for 2029-30 is likely to be 60.63 GW (18.98 GW PSP and 41.65 GW BESS) with storage of 336.4 GWh (128.15 GWh from PSP and 208.25 GWh from BESS).
- The projected gross electricity generation (BU) during the year 2029-30 is likely to be 2440.7 BU comprising of 1364.5 BU from Thermal (Coal, Gas and Lignite), 984 BU from RE Sources (including 222.5 BU from Hydro), and 92.2 BU from Nuclear. It is estimated that non-fossil fuels generation contribution is likely to be around 44% of the gross electricity generation during the year 2029-30.
- Several scenarios viz. Delayed Nuclear capacity addition, Delayed Hydro based capacity addition, Higher Demand requirement (Peak demand and energy requirement increases by 5%), conservative scenario (considering historical trends of capacity addition for different technologies) were studied to assess the capacity addition requirement to meet the projected demand in the year 2029-30 corresponding to different plausible situations considered in the respective scenarios. It is seen that apart from under construction coal-based capacity of 26.9 GW, the additional coal-based capacity required till 2030 may vary from 12.7 GW to around 19.1 GW across various scenarios. It is also seen that the BESS requirement in 2030 is varying from 22.6 GW/113.1GWh to 49.3 GW/246.9GWh across different scenarios studied.
- Hourly dispatch studies carried out for the year 2029-30 on an hourly basis suggest that with the aforementioned capacity mix, the hourly demand is likely to be met on each of the 365 days reliably while honouring various technical system constraints. Dispatch modelling validates that the optimal resource mix can meet demand in every hour of the year i.e., there is no loss of load, even during days when the system is stressed, such as days of peak load, highest net load, highest RE variability, etc.
- It has been observed that VRE based generation which may not be absorbed during the year 2029-30 is likely to be around 0.78% (considering 55% Minimum Power Load of Coal capacity). It decreases to 0.25% at 40% Minimum Power Load.
- It was observed that the likely RE generation which may not be absorbed in the system on some days in 2029-30 is up-to 4.94% (During high solar months). The Non absorption of RE arises due to the nature of load curve and generation profile of solar and wind and operating constraints of thermal units i.e., minimum technical constraints, gas availability, minimum flow requirement of hydro plants etc.

- Integrating high shares of renewable energy which is inherently variable and non-dispatchable brings with itself the challenge of increased flexibility requirement in the grid. To accommodate the variability and uncertainty of generation from RES, the conventional generating plants must be made flexible.
- The average PLF of the total Installed coal capacity of 251 GW is projected to be about 60.3% in 2029-30. The coal requirement for the year 2029-30 has been worked out to be about 1019.6 MT considering specific coal consumption of 0.666 kg/kWh + 1% transportation loss.
- The CO_2 emissions from the power sector during the year 2029-30 is likely to be 1114 MT. The average emission factor is likely to reduce to 0.477 kgCO2/kWh $_{net}$ by the year 2029-30.