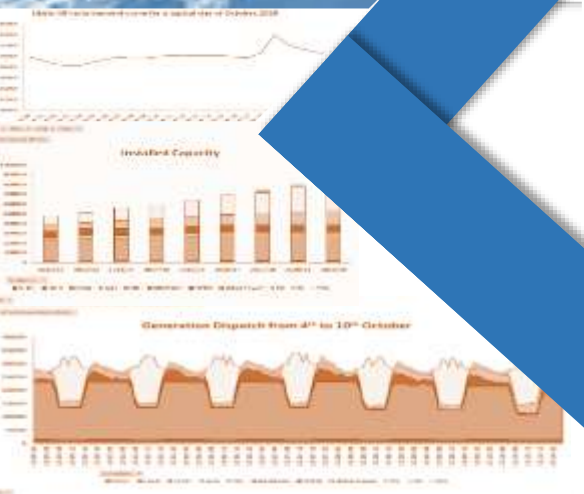

# REPORT ON OPTIMAL GENERATION CAPACITY MIX FOR 2029-30

JANUARY 2020


GOVERNMENT OF INDIA
MINISTRY OF POWER
CENTRAL ELECTRICITY AUTHORITY

# REPORT
# ON
# OPTIMAL GENERATION CAPACITY MIX FOR 2029-30

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**MINISTRY OF POWER**
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***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.*

# Executive Summary

The world today is witnessing several kinds of technological disruptions in different sectors. One of the likely disruption in power sector can be replacement of thermal based generation with Renewable energy generation complimented with energy storage technology. This has been possible with the downward trend of cost of solar panels and newer technology options like battery energy storage systems. In fact, the reduction in cost projections is very aggressive for Battery Energy Storage technology to render them financially viable in near future. In this context, planning for optimal generation capacity mix gains tremendous importance so as the future generation capacity mix is cost effective as well as environmental friendly, a horizon of 10-12 years is sufficient to gear up the systems and policies in the right direction to achieve the optimal generation mix. Keeping this in perspective, the study year of 2029-30 has been considered.

Optimal generation capacity mix is a study primarily aimed at finding out 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 as per 19th Electric Power Survey. The study 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.

CEA has carried out a mid-term review of National Electricity Plan notified in March'18 and assessed the likely installed capacity for the year 2021-22. The installed capacity projected in the midterm review of National Electricity Plan (NEP) has been taken as input to find out the requirement of future generation capacity mix to be built up by the end of the year 2029-30. The technical and financial parameters of different generation technologies have been considered as per National Electricity Plan. Globally many grid scale energy storage systems are commercially available or are at nascent stages of development. However, in the studies only commercially available storage technologies like Pumped hydro storage systems and battery energy storage systems are modelled, as the associated technical and cost data was available.

The short term studies to assess the economic hourly generation dispatch and adequacy of the capacity mix obtained from long term generation planning studies for the year 2029-30 have been carried out. 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. Due to the technical/operational constraints, the generation from RE sources may not be fully absorbed in the system on few days of the year. The report also assesses the impact on RE absorption by reducing presently stipulated technical minimum load of coal-based plants.

Sensitivity analysis for contingency scenarios is carried out by reducing available energy from RE sources and hydro power plants to test the system resilience. Impact on $CO_2$ emissions due to part load efficiency loss of coal based power plants has also been studied.

The study has considered a single demand node for the country and does not consider any transmission constraint in the year 2029-30.

Various stakeholders have submitted their comments on the draft report published on CEA website in July 2019. The comments received on the draft report by various stakeholders have been incorporated in the final study. Additional scenarios due to uncertainties associated with demand forecast and battery cost trajectory have also been included in the final study.

# INDEX

# 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 Dhirubhai 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** | Regasified Liquefied Natural Gas |
| **UNFCCC** | United Nations Framework Convention on Climate Change |

# 1. Introduction

Electricity is one of the key enablers for achieving socio-economic development of the country. The economic growth leads to growth in demand of power. Generation capacity augmentation is the most vital component amongst various modes adopted for meeting the ever-increasing demand of power to achieve the targeted growth rate.

After the enactment of Electricity Act, 2003 generation has been delicensed which has given impetus to the generation capacity addition and led to huge coal based generation capacity addition during $11^{th}$ and $12^{th}$ plan. India has marched ahead in the Power Sector taking huge strides in every sector of electricity viz. Generation, Transmission and Distribution. The per capita electricity consumption has increased from 592 kWh during 2003-04 to 1181 kWh during 2018-19. Consequently, the gap between electricity demand and supply has reduced drastically in the recent years. Presently, country is having enough generation capacity to meet its electricity demand. The supply gap of peak electricity demand and electrical energy requirement during the year 2018-19 was only 0.8% and 0.6% respectively. However, huge capacity addition in the recent years has raised concerns related to under-utilization of the coal based capacities leading to stressed assets in the sector. The PLF of coal-based plants has reduced to 61.07% during 2018-19 from 78.6% during 2007-08. Therefore, there is an increasing need to plan capacity addition optimally in view of the limited availability of fuel resources for generation, new sources of generation and environmental concerns.

The world is focusing on environmental issues, especially climate change and therefore the idea of growing sustainably has taken centre stage globally. In view of this, all countries across the globe have been actively engaged in climate negotiations on different platforms viz. UNFCCC. Consequently, the world has started moving towards carbon free energy. India being an active participant globally has started taking initiative towards sustainable development and cleaner environment.

Towards realizing the objective of carbon free energy, India has set for itself a target of installed capacity of 175 GW from Renewable Energy Sources (RE) by March 2022. To further address the environmental issues arising from the obnoxious emissions, more efficient supercritical coal based units are being commissioned and old and inefficient coal based capacity is being retired. Environmental issues along with the reduction in cost of renewable energy sources (solar PV and wind) have given a push to the solar and wind based power generation technologies. The capital cost of renewable (solar PV and wind) technologies for power generation is becoming competitive day by day with the coal based generation. These technologies are carbon free and will help to achieve the sustainable development programme of the country. However, the intermittency associated with the RE technologies is a limitation, which needs to be addressed in the power system. One of the options which can help in large scale integration of RE generation sources can be adoption of grid scale energy storage technologies which can complement RE generation sources. Storage Hydro plants/ Pumped storage plants can be highly useful for facilitating integration of high variable RE power into the power system. While other new storage technologies are in nascent stages of development, grid scale battery energy storage systems are becoming attractive globally due to rapidly reducing cost with the technological advancement. The world is anticipating that the grid scale energy storage technologies may help to absorb more RE economically into the power system in the near future.

The requirement of the energy storage systems can be fulfilled with any commercially viable energy storage technology suitable for grid scale applications.

## 2. Objective of the Study

**To find out the optimal generation capacity mix to meet the projected 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 technical 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 including Pumped Storage, Nuclear, Natural gas.

- Renewable Energy Sources- Solar, Wind, Biomass, Small Hydro, etc.
- New Technologies – Grid scale battery energy storage systems.

**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 realistic projections regarding their financial and technical parameters.

# 3. Why 2029-30?

To achieve the target of RE installed capacity of 175 GW by 2022, India has taken several policy initiatives for encouraging investment in RE Generation sources. National Electricity Plan has also laid its emphasis on RE integration and detailed studies have been carried out in NEP for the year 2021-2022 to analyze the power scenario with 175 GW of RE capacity in the Grid. Further, NEP has also given a perspective scenario for 2026-27 assuming 100 GW of capacity addition from RE during the period 2022-27 in view of the consistency in policy push for RE.

India is working towards low carbon emission path while meeting its developmental goals. In this regard, India is aiming to have 40 % of the total installed capacity by the year 2030 based on non-fossil fuel sources as submitted in Intended Nationally Determined Contributions (INDCs). This phase of transition warrants a detailed study of the power scenario in the year 2030.

Grid scale battery energy storage technologies have started gaining popularity globally as their cost of installation has been reducing drastically over the years. It is anticipated that battery energy storage technologies would become financially viable and complement RE as a prominent generation source in coming years. However, India has a large fleet of existing pithead coal power plants, which provide quite cheap electricity. In view of incoherence between peak demand and RE peak generation, hydro and flexible coal plants can provide the essential support for grid stability.

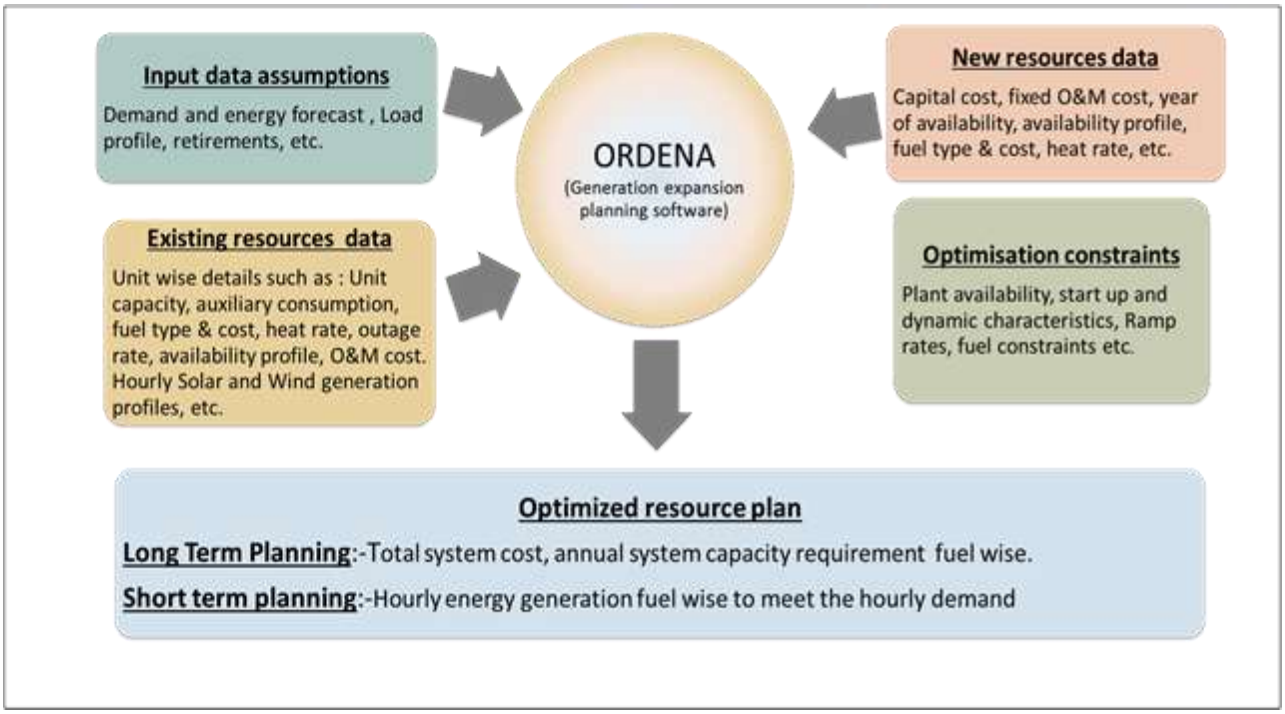
To address the above issues and to optimally utilize the available resources the least cost generation capacity expansion needs to be planned in optimum manner to meet the forecasted peak electricity demand and electrical energy requirement of the country in future. Therefore, there arises a need for detailed generation expansion planning studies for power scenario in 2030 where India can take the carbon-free growth path along with optimizing generation from different sources in most cost-effective manner. In this context, planning for optimal generation capacity mix gains tremendous importance to ensure future generation capacity mix is cost effective as well as environmental friendly. A horizon of 10-12 years is sufficient to gear up the systems and policies in the right direction so as to achieve the optimally planned generation mix. The study year 2029-30 has been considered keeping this in perspective.

# 4. Generation Expansion Planning Tool

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 namely ORDENA. 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 1**.

**Exhibit 1**



## 5. Present Installed Capacity

Total Installed Capacity of the country as on 30.09.2019 was 363.4 GW, which comprise of 45.4 GW from Hydro, 228.6 GW from Thermal, 82.6 GW from R.E.S and 6.8 GW from Nuclear. The detailed sector and fuel wise breakup of the total installed capacity as on 30.09.2019 and energy contribution from different sources during 2018-19 is given in **Table 1** and **Exhibit 2** respectively.

**Table 1**

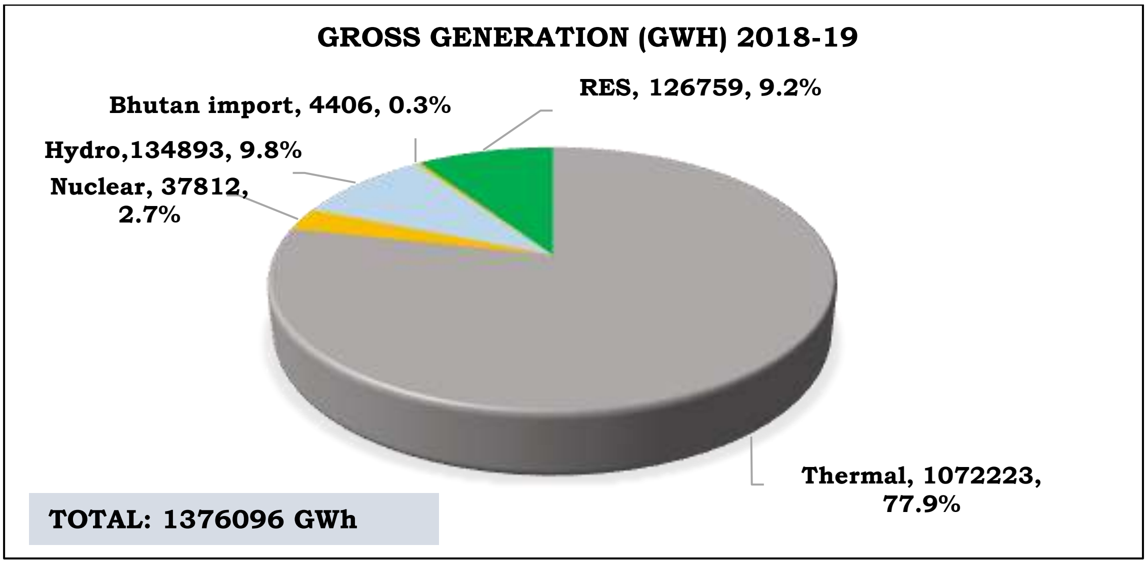
**INSTALLED CAPACITY AS ON 30.09.2019**

(FIGURES IN MW)

| Sector | Hydro | Thermal | | | | | Nuclear | R.E.S (MNRE) | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | Coal | Lignite | Gas | Diesel | Total | | | |
| State | 26958.50 | 65061.50 | 1290.00 | 7118.71 | 236.01 | 73706.21 | 0.00 | 2350.0 | 103014.7 |
| Private | 3394.00 | 74173.00 | 1830.00 | 10580.60 | 273.70 | 86857.30 | 0.00 | 78607 | 168858 |
| Central | 15046.72 | 57660.00 | 3140.00 | 7237.91 | 0.00 | 68037.91 | 6780.00 | 1632 | 91496.9 |
| **Total** | 45399.22 | 196894.50 | 6260.00 | 24937.22 | 509.71 | 228601.42 | 6780.00 | 82589 | **363370.0** |
| **%** | 12.5% | 54.2% | 1.7% | 6.9% | 0.1% | 62.9% | 1.9% | 22.7% | 100.00 |

NOTE:- I) I.C. does not include benefits from projects in Bhutan.
II) R.E.S. Includes SHP – Small Hydro Power, B.P. – Biomass Power, B.G. - Biomass Gasifier, U&I – Urban & Industrial Waste

**Exhibit 2**




## 6. Generation Capacity mix of the country

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 13% presently. Penetration of solar and wind capacities along with bigger sizes of coal based units, transition to super critical coal based technology etc. has taken place over these years. The probable 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 has 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 45% by the year 2018. 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 domestic gas and high cost of imported LNG. The country's installed capacity mix has seen growth in nuclear-based capacity from 4$^{th}$ five-year plan onwards and has grown up to 2% of the installed capacity by 2018 and further there are plans to increase this share.

India being richly endowed with renewable energy sources has achieved significant capacity addition in the renewable energy sector in the recent times. With environmental concerns gaining tremendous importance, India has now committed to increase the share of renewables in an unprecedented manner and committed to increase the installed capacity of renewables to 175 GW by the year 2021-22.

**Exhibit 3** and **Exhibit 4** depicts the capacity and generation mix historically. It can be seen that 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 3**

**Installed capacity mix of the country since the year 1980**

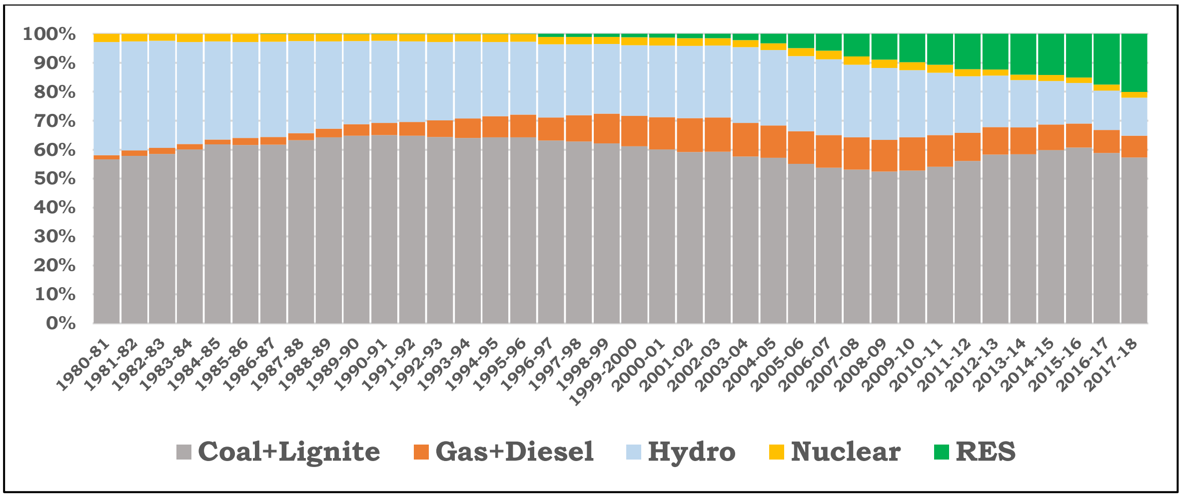
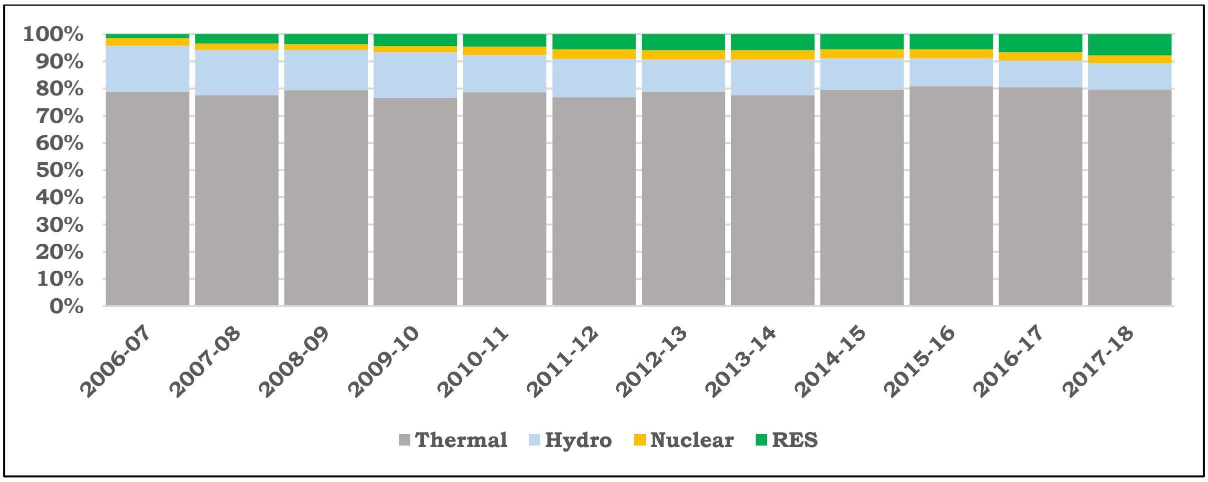



**Exhibit 4**

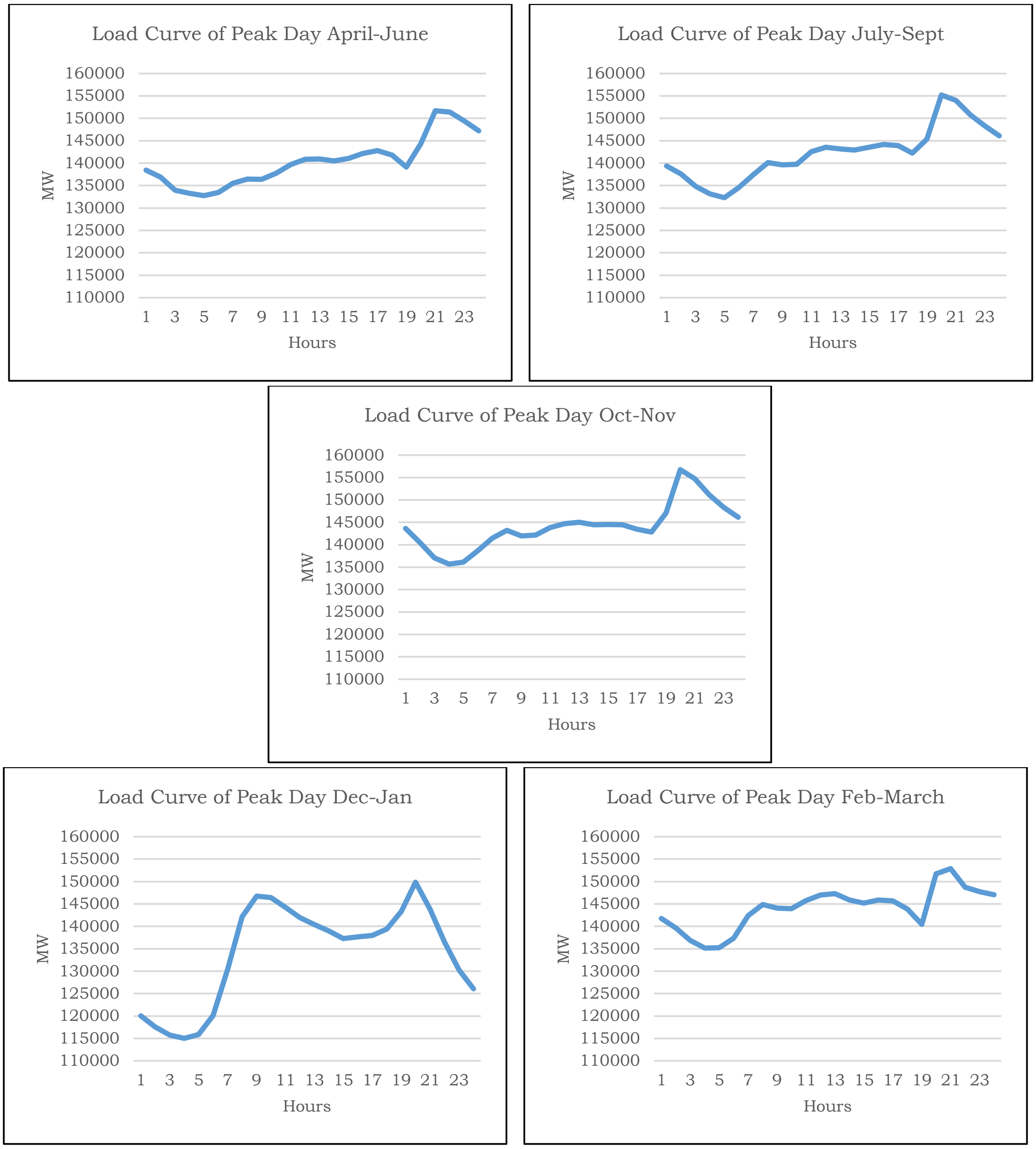
**Generation mix of the country since the year 2006**




## 7. Present Load Profile of the country

The country's load profile indicates that peak load is generally observed during morning hours and evening hours. However, the evening peaks are higher than the morning peaks. The All India peak load is observed generally in the month of September/October (load curve of the year 2014-15, 2015-16 and 2016-17). The load curve of the country varies significantly during different seasons and the same is shown in **Exhibit 5**.

**Exhibit 5**




# 8. Optimal Generation Capacity Mix studies for the year 2029-30

Studies have been carried out to find out the optimal generation capacity mix to meet the peak electricity demand and electrical energy requirement for the year 2029-30 with the objective to minimize the total system cost subject to various technical/financial constraints.

## 8.1 Inputs for the Study

i. CEA has carried out midterm review of the National Electricity Plan Vol I (Generation) to project the capacity addition by 2021-22. The generation capacity mix for the year 2021-22 as projected in the midterm review of

National Electricity Plan (NEP) Vol I (Generation) has been considered as the base capacity for the study.

**ii.** The projected installed capacity by the end of 2021-22 as per midterm NEP review is 4,76,431 MW (44,989 MW Hydro, 5246 MW PSP; 2,15,773 MW Coal; 25,343 MW Gas; 10,080 MW Nuclear, 5,000 MW small Hydro, 10000 MW Biomass, 100,000 MW solar and 60,000 MW wind) and has been considered as the base capacity (**Table 2**). Additionally, hydro imports totaling to 2136 MW have been considered till 2021-22. **The base year of the study has been considered as 2021-22.**

**Table 2**

| Technology | Capacity(MW) |
|---|---|
| Hydro* | 44,989 |
| Pumped Storage | 5246 |
| Coal | 2,15,773 |
| Gas | 25,343 |
| Nuclear | 10,080 |
| Solar | 1,00,000 |
| Wind | 60,000 |
| Biomass | 10,000 |
| Small Hydro | 5,000 |
| **Total IC by 2021-22** | **4,76,431** |

*Excluding hydro imports of 2136MW

iii. The study period from the year 2022-23 to 2029-30 has been considered to arrive at the optimal generation capacity mix for the year 2029-30.

iv. The 19th Electric Power Survey (EPS) (published by CEA) projections for peak electricity demand and electrical energy requirement have been considered for the studies. Electricity demand assessed by the 19th EPS Report gives the year-wise demand upto 2026-27 and then long term demand projections of the year 2031-32 with estimated CAGR for peak demand and energy requirement. The demand for 2029-30 has been assessed with a CAGR of peak demand of 4.4% and that of energy requirement of 4.33% from 2027-2032.

v. The estimated peak electricity demand (GW) and electrical energy requirement (BU) in the years 2021-22, 2026-27 and 2029-30 are given in **Table 3**.

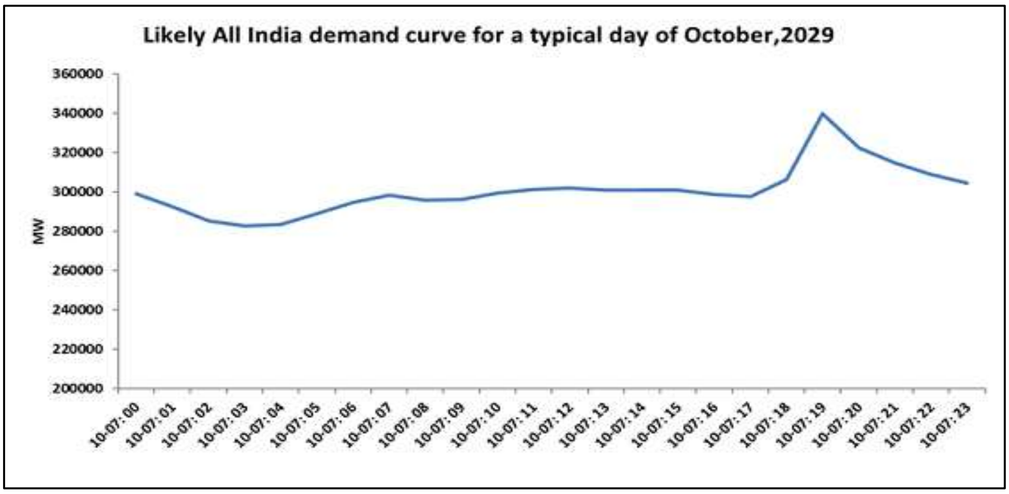
**Table 3**
**Projected Electricity Demand (As per 19th EPS)**

| Year | Electrical Energy Requirement (BU) Ex Bus | Peak Electricity Demand (GW) |
|---|---|---|
| **2021-22** | 1566 | 225.751 |
| **2026-27** | 2047 | 298.774 |
| **2029-30** | 2325 | 339.973 |

vi. The 19th EPS estimates the All India Peak and Electricity demand on the National electricity grid in future years. This demand is exclusive of the demand being met by solar roof top installation. Some of the electricity demand is likely to be met locally through rooftop solar installations, leading to less requirement from the National Grid. To capture the hourly and seasonal variation of the grid connected solar roof top along with grid connected large solar PV plants, the energy contributed by the solar roof top has been added to the energy requirement projected by the 19th EPS for the study purpose. It has been estimated that the energy contribution from the solar roof top during the year 2029-30 is likely to be 75 BU. Therefore, the energy requirement for the year 2029-30 considered for the study has been taken as 2400 BU( 2325 + 75). However, the peak load during the year 2029-30 for the study has been considered as 340 GW (as per 19th EPS) as there is no peak contribution from solar roof top (All India peak load occurs in the evening).

vii. The most important aspect of any generation planning study is the annual hourly demand projections. Hence, the endeavor has been to meticulously project hourly demand for the year 2029-30. In this regard, the hourly demand profiles on all India basis of the years 2014-15, 2015-16 and 2016-17 have been studied to arrive at the most probable demand profile and the same has been extrapolated considering the peak electricity demand and electrical energy requirement for the study in the year 2029-30. The likely hourly demand curve for a typical day in October 2029 is shown as **Exhibit 6**.

**Exhibit 6**




viii. Study has been carried out considering the following technologies as shown in **Table 4**.

**Table 4**

**Technologies considered for the study**

| Conventional Technologies | Renewable Technologies | Storage technologies |
|---|---|---|
| Coal | Solar | Pumped Storage |
| Gas* | Wind | Battery Energy Storage |
| Nuclear (LWR) | Biomass | |
| Nuclear (PHWR) | Small Hydro | |
| Large Hydro | | |

*No additional gas based capacity has been considered in view of limited availability of domestic gas

ix. Under construction capacity of 6,494 MW of hydro, 1705 MW of pumped storage has been considered during the study period (2022- 2030) as planned.

x. Hydro imports of the order of 3,720 MW from neighboring countries have been considered during the study period (2022- 2030).

xi. Hydro stations totaling to 12,210 MW that have been concurred by CEA have been considered as candidate plants during the period 2022-30.

xii. PSP stations of about 6020 MW which have been concurred or are under survey and investigation(S&I) have been considered as candidate stations during the study period (2022-30).

xiii. Capacity totaling to 8,900 MW of nuclear (as per DoAE) has been considered as planned capacity for the study period. (2022-30)

xiv. Nuclear capacity of about 12,000 MW that has got in principle approval has been considered as candidate plants for the study period (2022-30).

xv. Retirement of old coal based units totaling to 25,252 MW has been considered for the period 2022-30.

xvi. Under-construction coal based capacity of 8630MW has been considered as planned (likely to be commissioned after the year 2022) during the study period (2022-30).

xvii. Coal based supercritical and ultra-supercritical units of 660 MW and 800 MW have been considered as candidate plants.

xviii. The study has been done with high level of granularity and the model has been provided with unit wise characteristics like installed capacity, commissioning year, fuel type, heat rate, outage rate, maintenance duration, fuel cost, fixed O&M cost, start up/down time and cost, ramp rates, minimum technical load, capital cost, peak contribution, hydro storage related data, Hydro seasonal energy, emission factors etc. in respect of all the existing, under construction, planned and candidate plants.

xix. The reducing trend of the capital cost of solar PV as well of Battery Energy Storage technology has been considered in the study.

xx. The deterioration in operational efficiency with part loading of units of thermal plants has been considered.

xxi. No additional gas-based capacity has been considered apart from existing capacity of 25,343 MW in view of shortage of domestic natural gas.

xxii. 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 to power stations.

xxiii. Due to seasonal availability of Biomass, fuel restriction for the Biomass has been considered.

xxiv. The actual 8760 hourly generation profile of solar and wind has been gathered from various states having RE generation. The average annual CUF of solar power plants has been estimated to be around 22 % and that of wind power plants as 25.21 % in the year 2029-30.

xxv. To capture the seasonal variation associated with hydro and RE generation, the 8760 hours of year have been divided into five seasons based on the demand pattern. The five seasons are as follows:

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

xxvi. The hydro energy availability varies significantly across the years as it depends on the monsoon rains in a particular year. Therefore, the actual monthly hydro generation of the existing hydro power plants for the years 2014-15, 2015-16, 2016-17 and 2017-18 has been studied 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 summed up to arrive at the seasonal energy. Each season has been further divided into blocks based on the RE generation profile for increasing the granularity and precision of the study. 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 outflow even 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.

xxvii. Constraint of maximum wind capacity of 140 GW by the year 2029-30 based on the MNRE projection has been considered.

xxviii. Details of the various inputs and assumptions are given in **Annexure-I**.

## 8.2 Energy Storage Systems

The next phase of energy transition driven by the large-scale deployment of variable renewable energy sources (VRES) like solar and wind power can be fully realized by key technologies of Energy Storage. The grid integration challenges of the intermittent generation sources ensuring quality of supply on real time basis along with the capability to store excess electricity over different time horizons (minutes, days, weeks) can be achieved by the electricity storage systems.

Many grid scale energy storage systems are commercially available worldwide which includes Pumped storage plants, Battery energy storage systems etc. However, many energy storage technologies like Molten rocks, flywheel, Super capacitors, Green Hydrogen are in nascent stages of development and projections in respect of costs, technical characteristics are not yet firmed up. Therefore, in the studies only commercially available storage technologies like Pumped hydro storage systems and battery energy storage systems are modelled.

### 8.2.1 Pumped Hydro Storage System

While many forms of energy storage systems have been installed globally, Pumped Storage Plants (PSP) are playing an increasingly important role in providing peaking power and maintaining system stability in the power system of many countries. Pumped storage technology is the long term technically proven, cost effective, highly efficient and flexible way of energy storage on a large scale to store intermittent and variable energy generated by solar and wind. PSPs improve overall economy of power system operation and reduce operational problems of thermal stations during low load period.

The other advantages of pumped storage technology are availability of spinning reserve at almost no cost to the system and regulating frequency to meet sudden load changes in the network. Also, PSPs provide environmental friendly large storage capacity compared to other storage options. It also has the ability to provide ancillary benefits such as flexible capacity, voltage support and Black start facility etc. Pumped storage technology has advanced significantly since its original introduction and now includes adjustable speed pumped turbines which can quickly shift from motor, to generator, to synchronous condenser modes, for easier and more flexible operation of the Grid. The concept of off-river PSP is getting popular in recent years due to huge benefits arising out of its less capital cost/operations. Therefore, with increased penetration of RES in the grid, PSPs can play a vital role in integration of RE sources in the national grid.

The study has considered proposed PSP projects which are either concurred or in advance stages of survey and investigation.

### 8.2.2 Battery Energy Storage Systems

The cost of Battery Energy Storage system has been estimated after consultation with the various battery manufactures/suppliers. The cost of battery energy storage system considered in the model includes cost of battery, inverter, Battery and Energy Management Systems and other costs (cabling and installation costs). The size of the battery estimated by the model is based on 100% depth of discharge. The actual size of the battery catering to 80% depth of discharge may be more by 25%. For modelling purpose the capital cost of the battery has been increased by 25% to account for the 80% depth of discharge. The cost trajectory for battery energy storage system is assumed to be reducing uniformly from ₹ 7 Cr in 2021-22 to ₹ 4.3 Cr in 2029-30 for a 4 hour battery system which also includes an additional cost of 25% due to depth of discharge. The O&M cost for the battery energy storage system has been considered as 2%.

## 8.3 Results of the Study

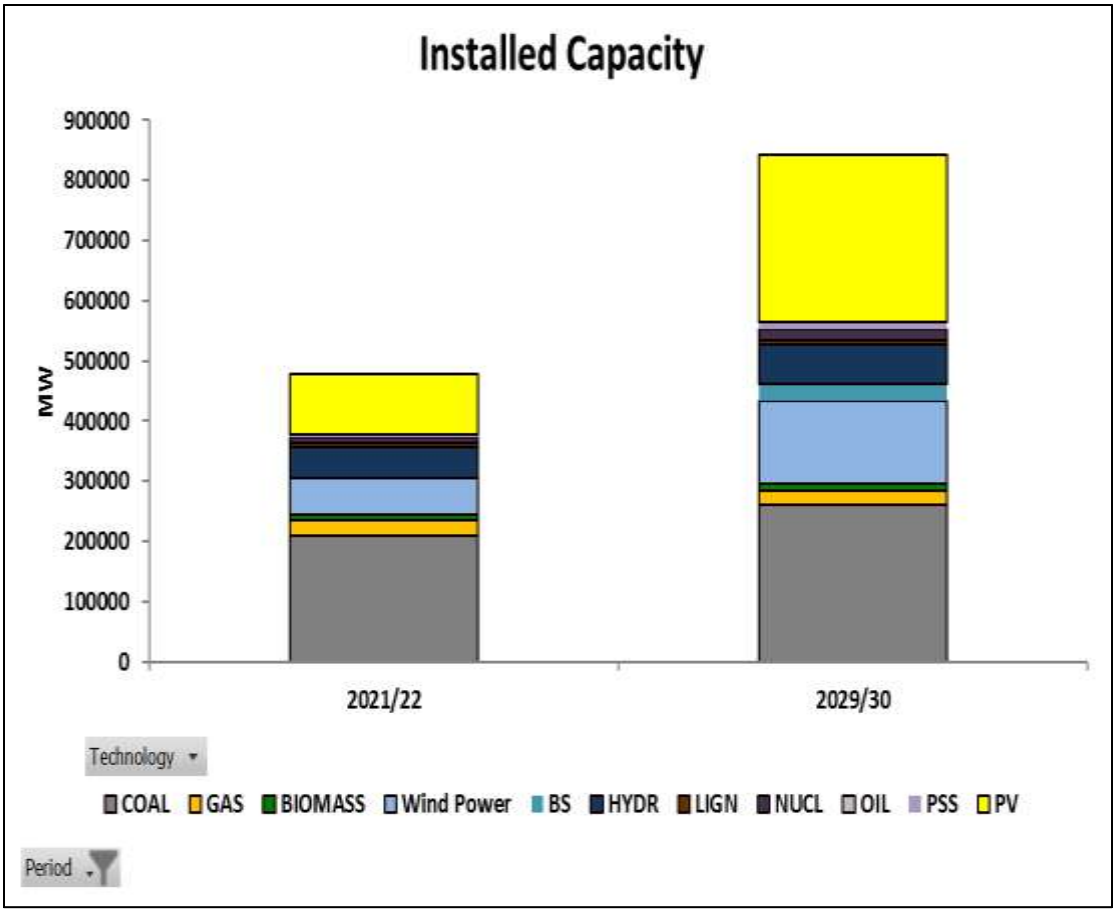
### 8.3.1 Long Term studies

Studies were carried out with the inputs/assumptions elaborated in section 8.1 using computer model ORDENA 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) is shown in **Exhibit 7**. Graphs given below are indicative and are not to the scale.

## Exhibit 7


Installed Capacity
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
MW
2021/22
2029/30
Technology
COAL
GAS
BIOMASS
Wind Power
BS
HYDR
LIGN
NUCL
OIL
PSS
PV
Period

The likely installed capacity by the end of the year 2029-30 is given in **Table 5** and **Exhibit 8**.

**Table 5**
**Likely Installed capacity by the end of 2029-30**

| Fuel Type | Capacity (MW) in 2029-30 | Percentage Mix (%) |
|---|---|---|
| Hydro * | 60,977 | 7.46% |
| PSP | 10,151 | 1.24% |
| Small Hydro | 5,000 | 0.61% |
| Coal + Lignite | 2,66,911 | 32.66% |
| Gas | 25,080 | 3.07% |
| Nuclear | 18,980 | 2.32% |
| Solar | 2,80,155 | 34.28% |
| Wind | 1,40,000 | 17.13% |
| Biomass | 10,000 | 1.22% |
| **Total** | **8,17,254** | |
| Battery Energy Storage# | 27,000MW/108,000MWh | |

* including hydro imports of 5856 MW # Active Battery Storage.

From the results, following is observed:

i. A candidate coal based capacity of 67,760 MW has been selected by model during the period 2022-30.

ii. A hydro capacity of 3,658 MW has been selected out of 12,210 MW of candidate hydro plants during the period 2022-30.

iii. Pumped storage plants of 3200 MW has been selected out of 6,020 MW of candidate Pumped storage plants during the period 2022-30.

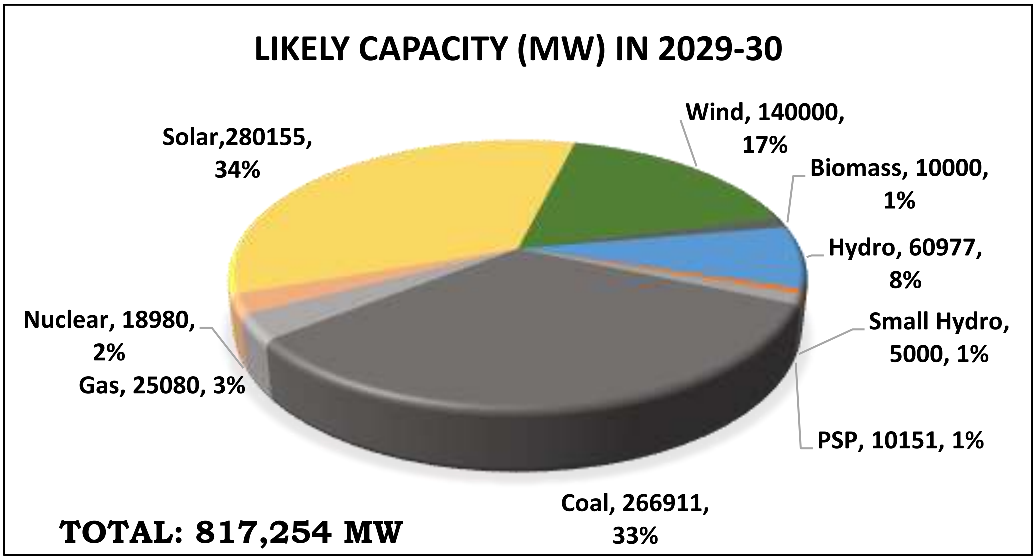
iv. Model has not selected any new candidate nuclear power plants apart from already planned projects during the period 2022-30.

v. Model has selected a solar capacity of about 180 GW and Wind capacity of 80 GW during the period 2022-30.

vi. It is seen from the results that renewable energy sources (solar + wind) installed capacity is likely to be about 420 GW( 280GW Solar + 140 GW Wind) by the end of year 2029-30 which is more than 50% of total installed capacity of 817 GW.

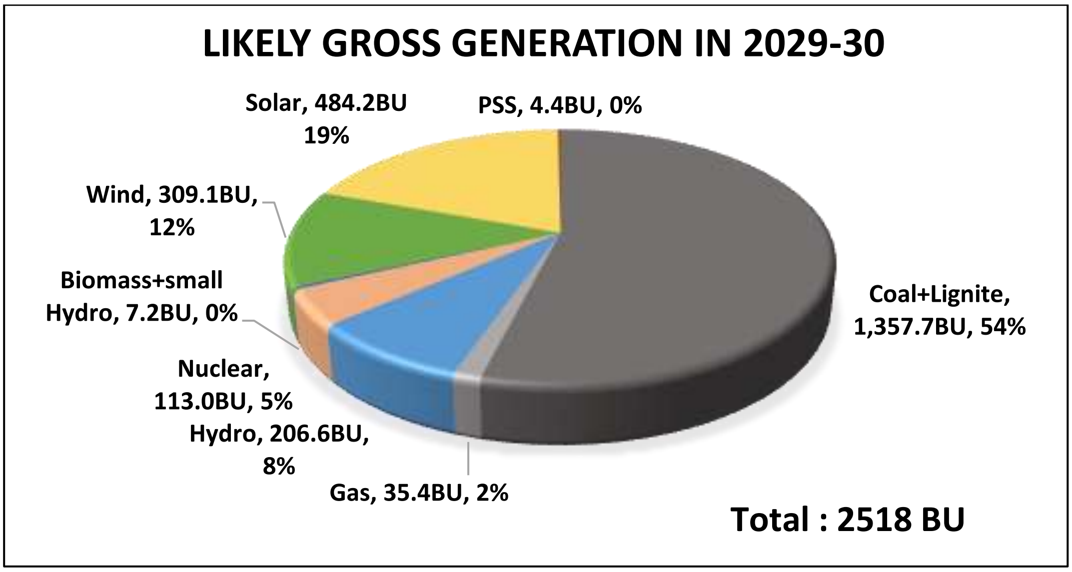
vii. A battery energy storage system of 27GW with four hour storage has been selected by the model during the period 2022-30.

**Exhibit 8**




The projected gross electricity generation (BU) during the year 2029-30 is likely to be 2,518 BU comprising of 1,393 BU from Thermal (Coal, Gas and Lignite), 801 BU from RE Sources, 207 BU from Hydro, 4.4 BU from PSS and 113 BU from Nuclear as shown in **Exhibit 9**.

**Exhibit 9**




* including Generation from hydro imports.

It can be seen from the above results that in the year 2029-30, non-fossil fuel (solar, wind, biomass, hydro & nuclear) based installed capacity is likely to be about 64% of the total installed capacity and non-fossil fuels contribute around 44.7% of the gross electricity generation during the year 2029-30.

### 8.3.2 Short Term studies - (Hourly Generation dispatch)

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 have 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 short-term studies to arrive at the least cost optimum hourly generation dispatch from the projected capacity for all 365 days throughout the year 2029-30.

To illustrate hourly generation dispatch patterns, few critical days w.r.t. system/grid operation are identified by analyzing the likely demand pattern and likely variable RE (Wind & Solar) generation during the year 2029-30. The details of typical days identified for the short term studies are given in **Table 6**. Graphs given in the results are indicative and are not to the scale.

**Table 6**

**Short Term scenarios considered (Critical Days)**

| Sl. No. | Scenario | Day |
|---|---|---|
| 1 | Peak Day / Max Energy demand day | 7th October, 2029 |
| 2 | Maximum VRE (Wind+ Solar) generation day | 3rd July, 2029 |
| 3 | Maximum Solar generation day | 25th March, 2030 |
| 4 | Minimum Solar generation day | 8th August, 2029 |
| 5 | Minimum Energy demand day | 14th December, 2029 |
| 6 | Minimum VRE (Wind+ Solar) generation day | 1st February, 2030 |
| 7 | Maximum Variation in demand day | 27th January, 2030 |
| 8 | Maximum Variation in Net demand day | 26th October, 2029 |

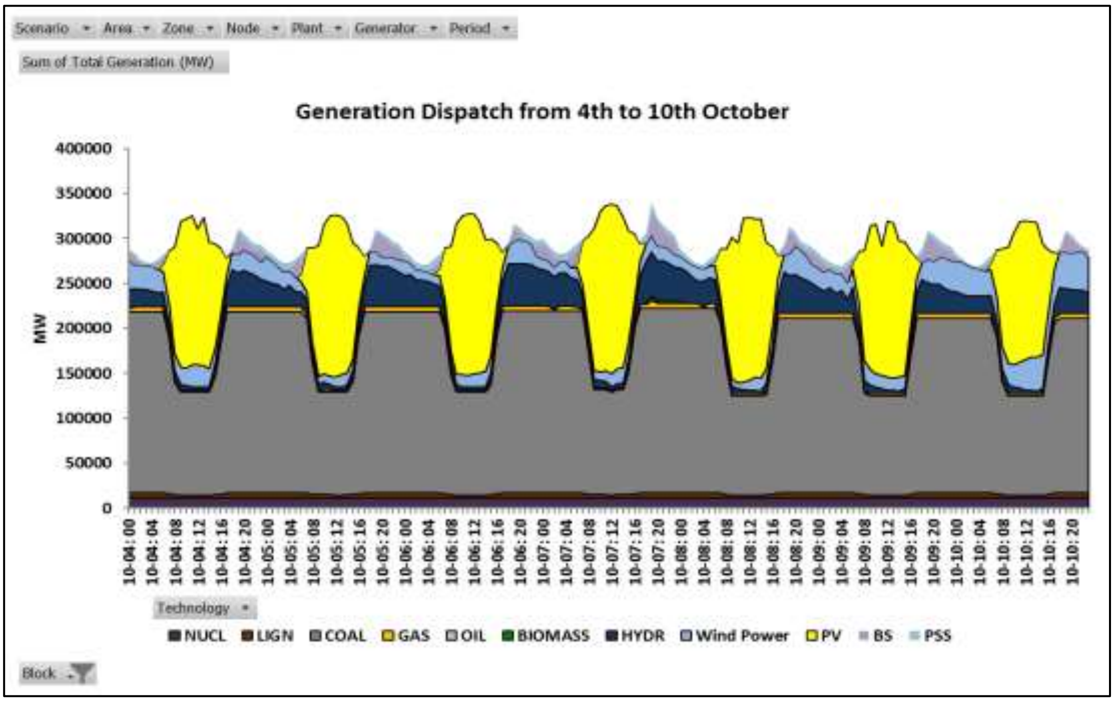
**Note: Dates are only indicative**

#### *8.3.2.1* Peak Day / Max Energy demand day – 7th October, 2029

One of the most critical day from power planning perspective is peak demand day and it has to be ensured that there will be adequate supply for meeting the peak demand whenever it occurs. This demonstrates the capability of the system for meeting the peak demand on other days as well. From the likely hourly demand profiles of 2029-30, it has been observed that the peak demand of 340 GW in the country may occur in the month of October and may likely to occur on 7th of October 2029. Analyzing the daily energy requirement of 2029-30, 7th October also happens to be the maximum energy requirement day (7.21 BU).

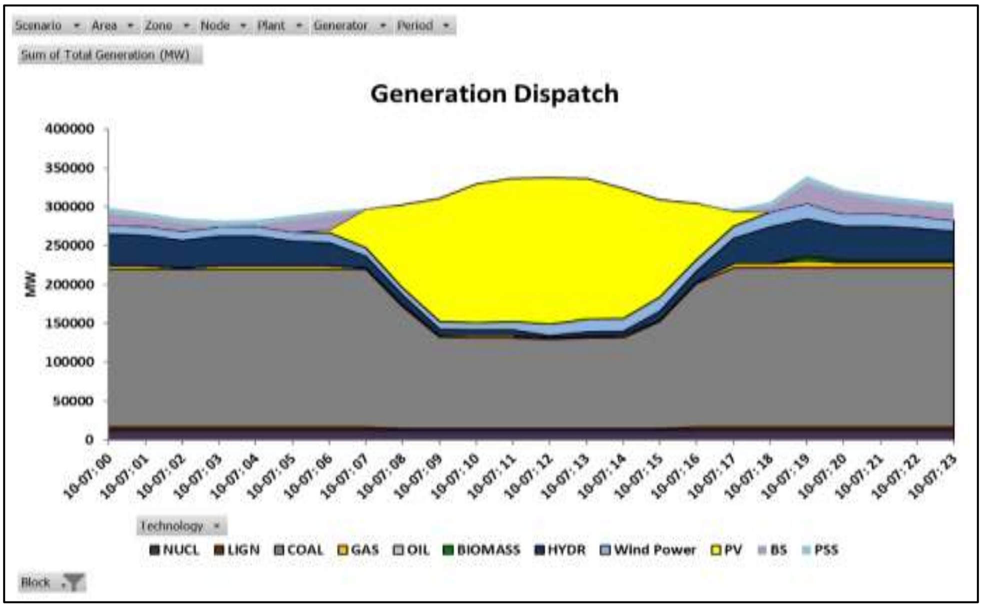
Typical generation dispatch for the week in which peak demand occurs is shown in the **Exhibit 10.**

**Exhibit 10**




Hourly generation dispatch for the peak day is shown in the **Exhibit 11**.

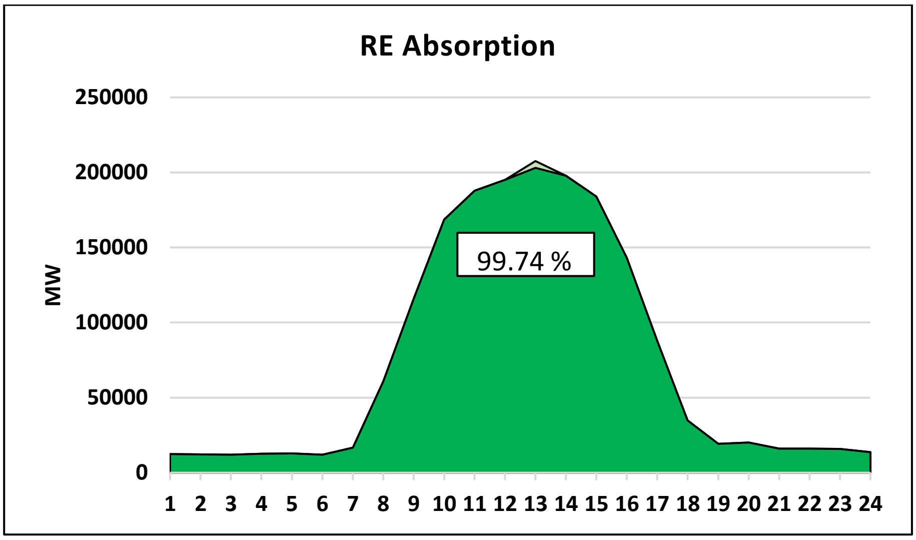
**Exhibit 11**



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 technical load(MTL) 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. However, RE generation could not be fully absorbed due to shape of load curve, minimum technical loading of the coal and gas plants etc. even when wind Capacity Utilization Factor (CUF) on the day is only 9.98% and solar CUF is 21.47%. The Gross PLF of the coal based capacity is likely to be 72. 58% on the day.

RE generation dispatch and absorption is shown in the **Exhibit 12**. The RE absorption on the peak day is likely to be around 99.74%.

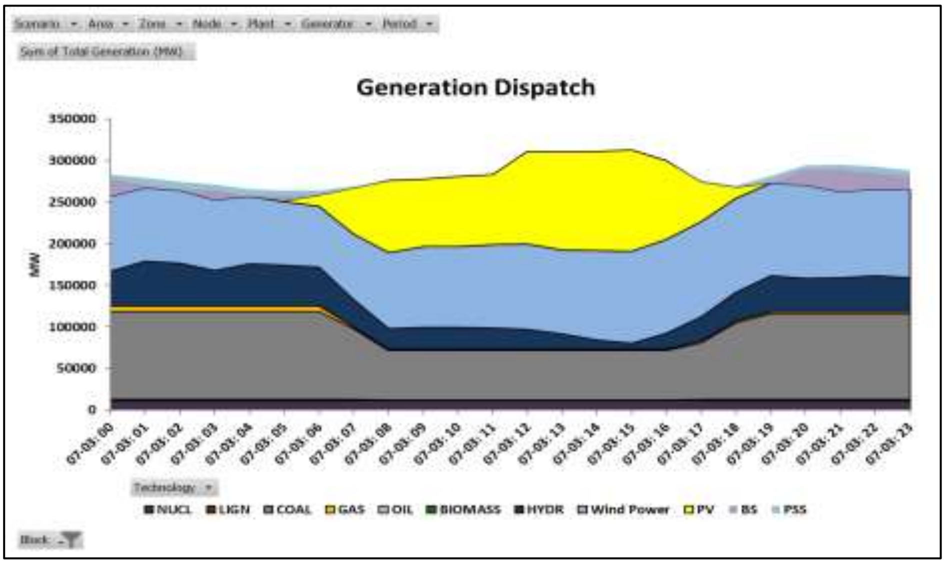
**Exhibit 12**




### 8.3.2.2 Maximum VRE (Wind + Solar) Generation day – 3rd July, 2029

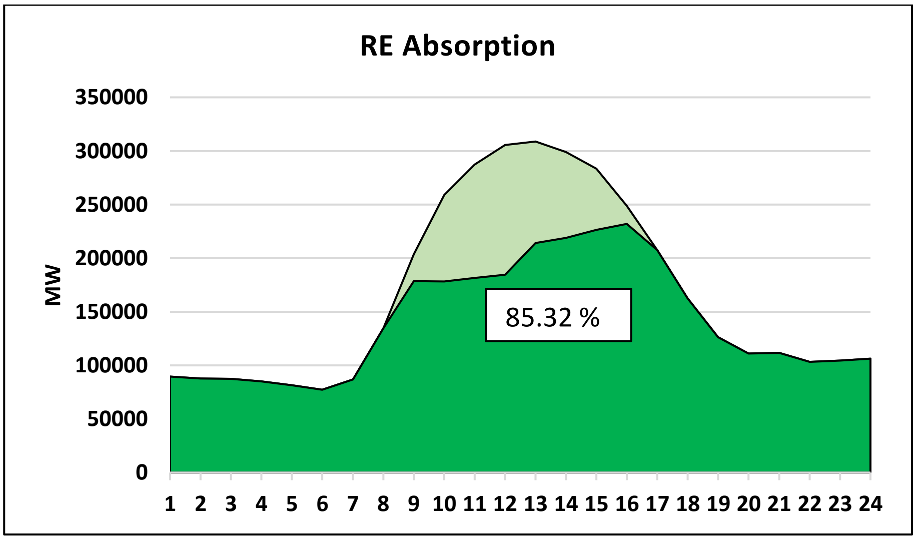
The system has to be resilient on the day when the maximum generation from RE (wind + solar) is likely to be available. The maximum generation from RE is likely to occur in the month of July, typically 3rd of July. The CUF of the wind capacity is likely to be maximum (69.79%) on this day. The hydro generation is also maximum during the month of July. Hourly generation dispatch for the maximum RE generation day is shown in the **Exhibit 13**.

Exhibit 13




It has been observed that on this day during which RE generation is maximum, the demand is likely to be fully met with the generation capacity mix obtained from the long-term studies. It has been observed that RE generation could not be fully absorbed on this day. The RE absorption on this day is likely to be around 85.32 %. RE generation dispatch and absorption is shown in the **Exhibit 14**. Due to higher availability of hydro and wind generation during the season, the annual maintenance of the coal plants may be taken up during this period

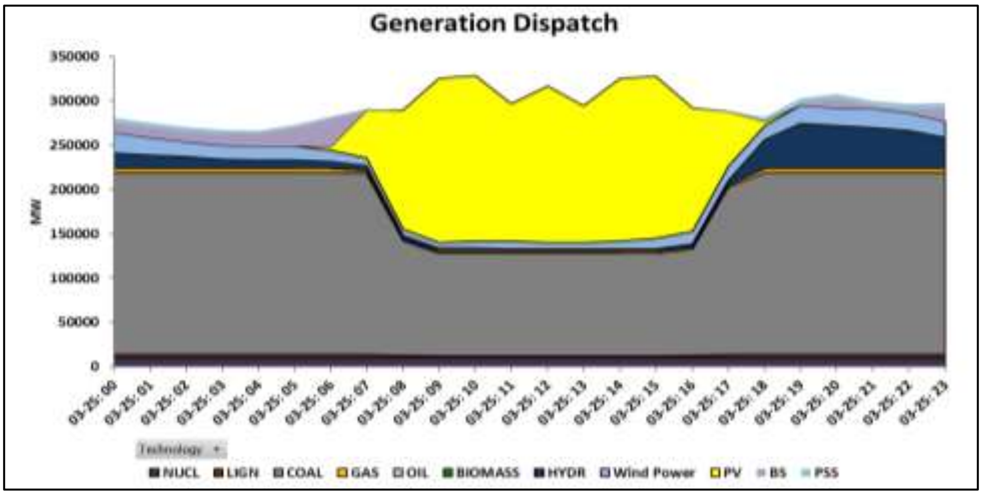
Exhibit 14




### 8.3.2.3 Maximum Solar Generation day – 25th March, 2030

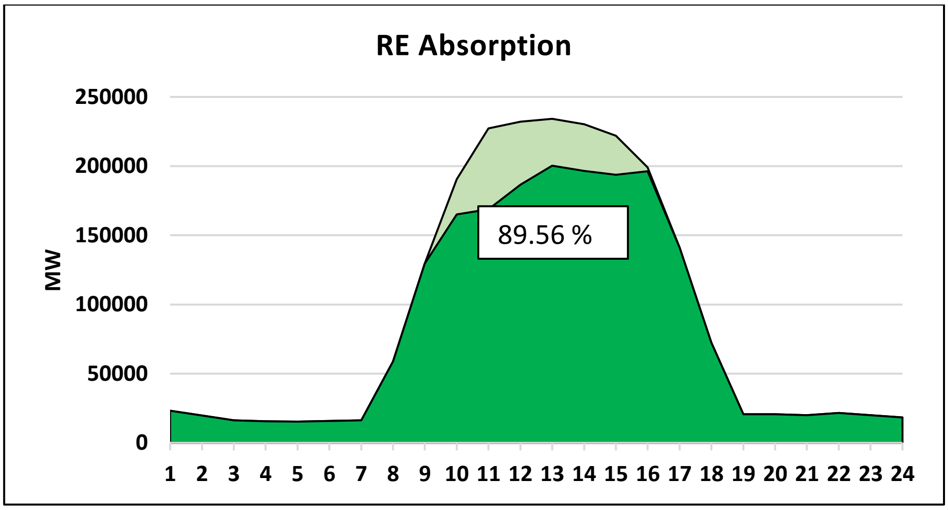
Studies have been carried out on the week containing maximum solar generation day i.e. 25th March, 2030 to assess the adequacy of supply and RE absorption. The CUF of solar capacity is around 27.45 % on this day. Hourly generation dispatch is shown in **Exhibit 15**.

**Exhibit 15**




It has been observed that on this critical day when solar generation is maximum, the demand is likely be fully met with the generation capacity mix obtained from the long term studies. It can also be seen that during the month of March, the hydro energy in the northern region is generally minimal. The wind generation also reduces during the spring season. Despite less hydro and wind generation, solar generation could not be fully absorbed due to technical constraints. The RE absorption on this day is likely to be around 89.56%. RE generation dispatch and absorption on this day is shown in the **Exhibit 16**.

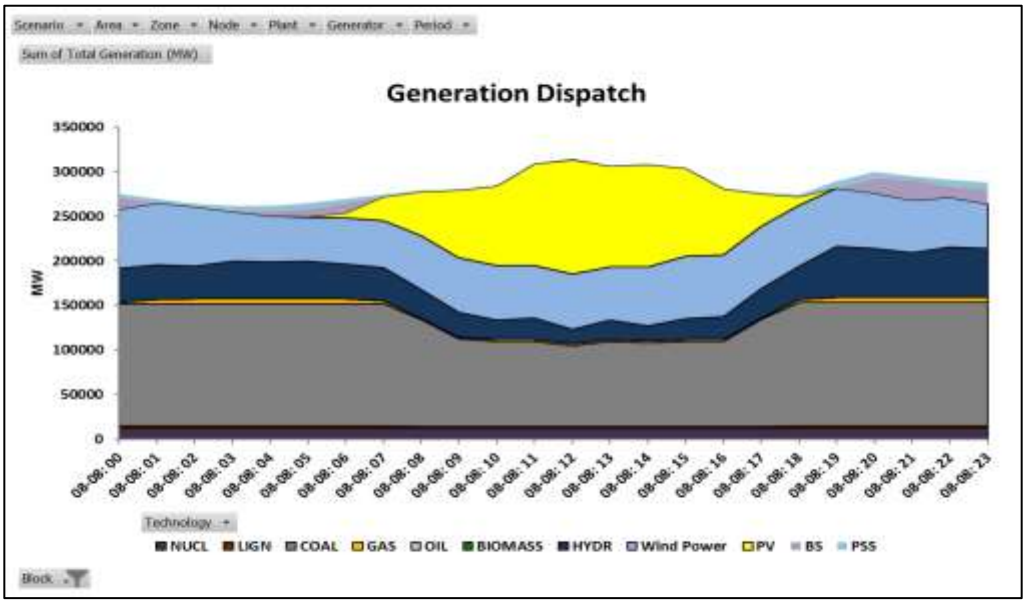
**Exhibit 16**




### *8.3.2.4* Minimum Solar Generation day – 8th August, 2029

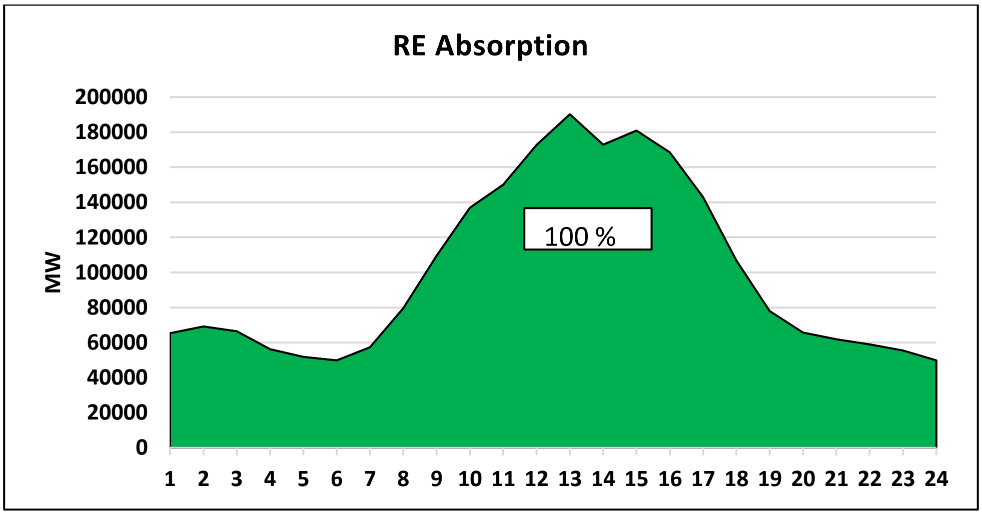
Studies have been carried out on the week containing minimum solar generation day i.e. 8th August, 2029 to assess the adequacy of supply and extent of RE absorption. The CUF of solar capacity is only 13.97%. Hourly generation dispatch on this day is shown in **Exhibit 17**.

**Exhibit 17**




It has been observed that the day when solar generation is minimum, the demand is likely to be fully met with the generation capacity mix obtained from the long term studies. This is due to significant availability of hydro and wind energy during monsoon season. It has been observed that RE generation is fully absorbed on this day as shown in the **Exhibit 18**.

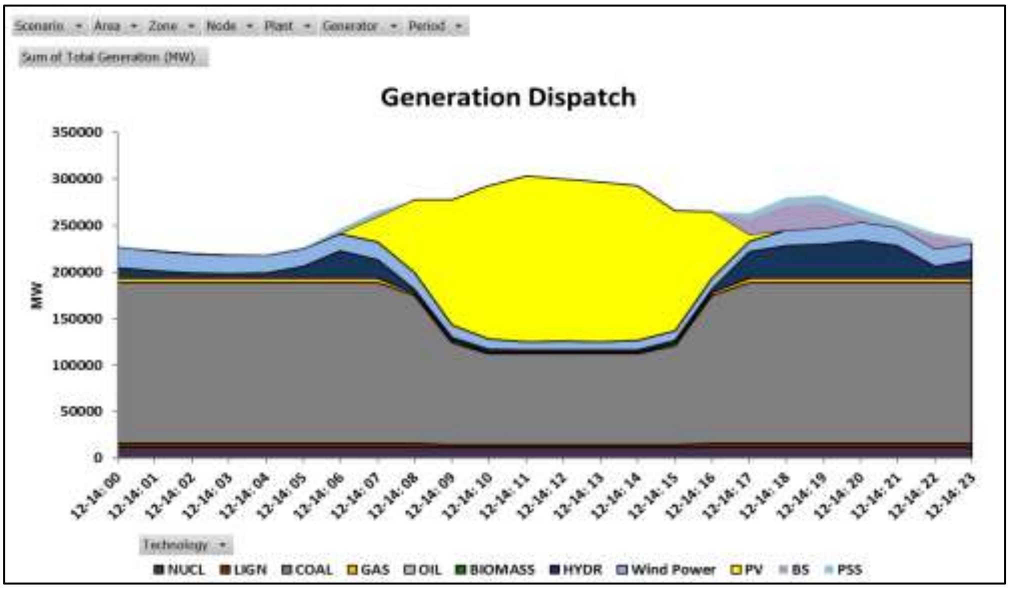
**Exhibit 18**




### 8.3.2.5 Minimum Energy Demand Day – 14th December, 2029

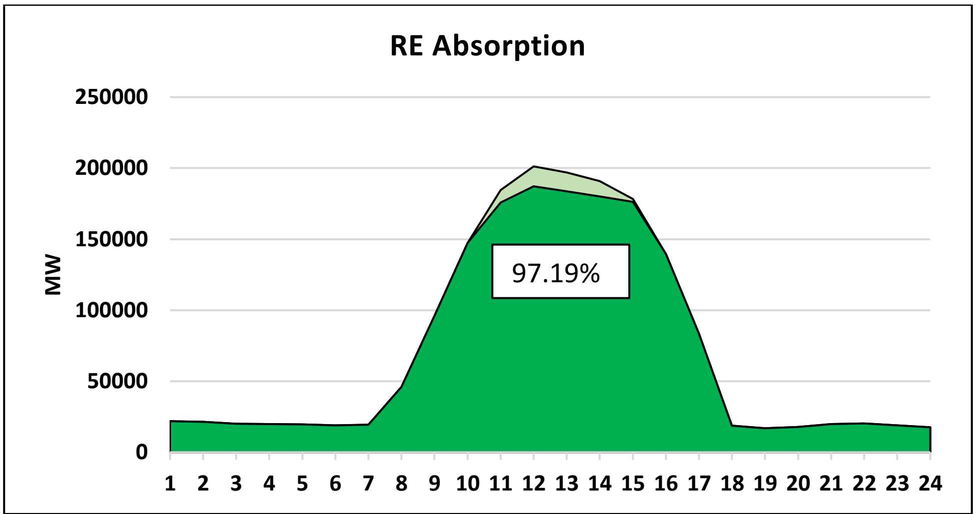
Studies have been carried out on the week containing minimum energy demand day i.e. 14th December, 2029 to assess the adequacy of supply and RE absorption. The energy requirement is only 6 BU on this day. Hourly generation dispatch is shown in **Exhibit 19**.

**Exhibit 19**




It has been observed that during this critical day when energy demand of the system is minimum, the demand is likely to be fully met with the supply side options as per the long-term studies. It is observed that despite hydro and wind generation being relatively less, RE absorption on this day is likely to be around 97.19%. RE generation dispatch and absorption on this day is shown in the **Exhibit 20**.

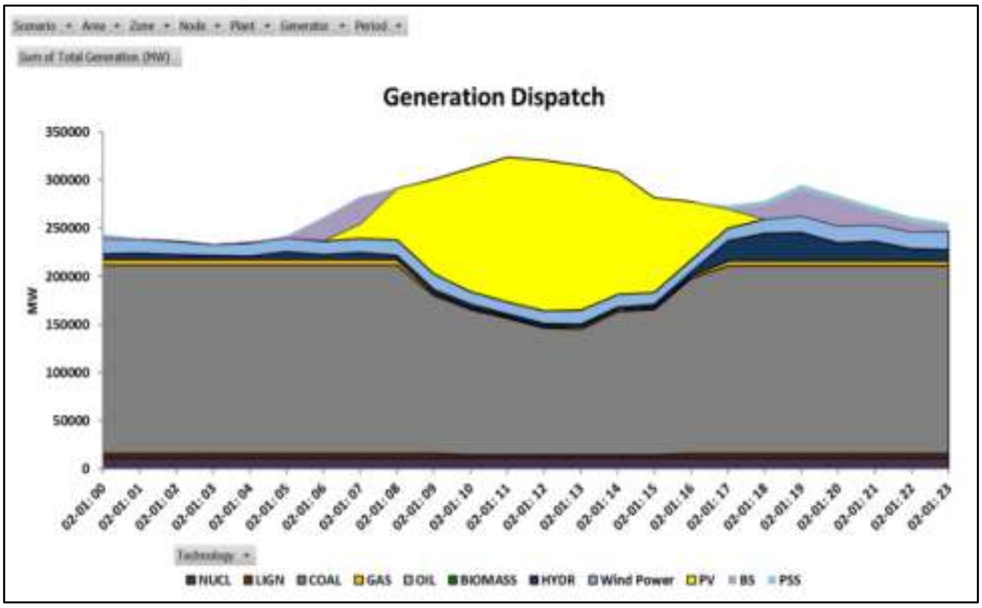
**Exhibit 20**




### *8.3.2.6* Minimum VRE Generation Day – 1st February, 2030

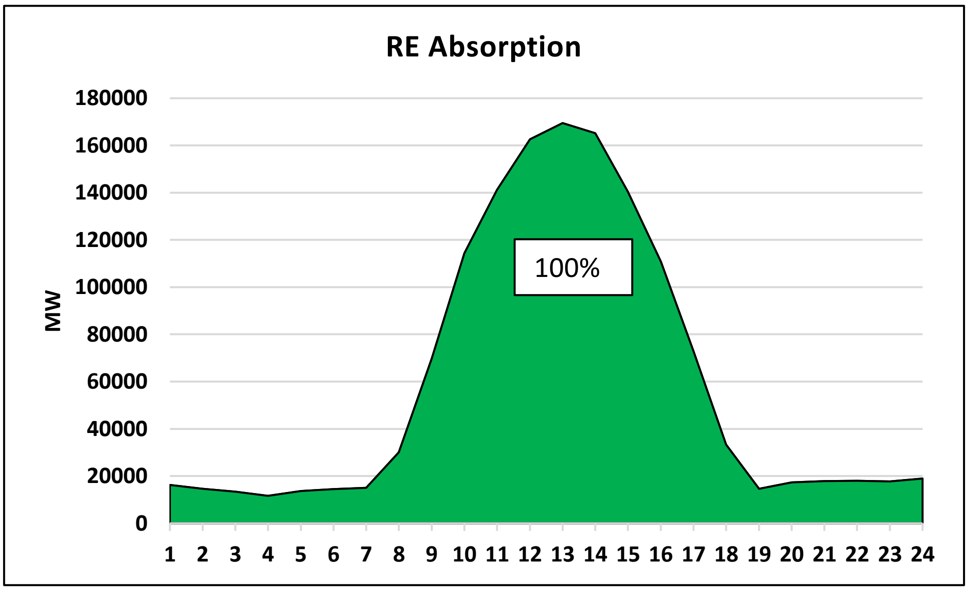
Studies have been carried out on the week containing minimum RE (solar + wind) generation day i.e. 1st February, 2030 to assess the adequacy of supply and extent of RE absorption. The CUF of solar and wind power plants is likely to be only 15.81% and 10.54% respectively on this day. It is observed that likely hydro generation is also low on this day. Hourly generation dispatch is shown in **Exhibit 21**.

**Exhibit 21**




It has been observed that on this day when the generation from RE is minimum, the likely to be be fully met with the supply side options as per the long term studies. It can be observed that the day when RE generation is minimum, the demand is also on the lower side and the conventional capacities are enough to meet the demand. The gross PLF of coal capacity on this day is likely to be around 73.91 %. It has been observed that RE generation is likely to be fully absorbed on this day as shown in **Exhibit 22.**

**Exhibit 22**




### *8.3.2.7* Maximum variation in net demand/demand days

Studies have also been carried out for the likely days when the difference in minimum to maximum demand is highest both for net demand as well as total demand. The hourly generation dispatch of the day has been studied to assess the ramping capabilities of the conventional generation to meet the peak demand. The maximum variation for net demand is likely to occur on 26th October, 2029 during which the maximum hourly net demand is 285 GW and minimum hourly net demand is 33 GW. The maximum variation in the total demand is likely to occur on 27th January, 2030 during which the maximum hourly total demand is 296 GW and minimum hourly total demand is 213.5 GW. Hourly generation dispatch for both days is shown in **Exhibit 23 & 24.**

**Exhibit 23**

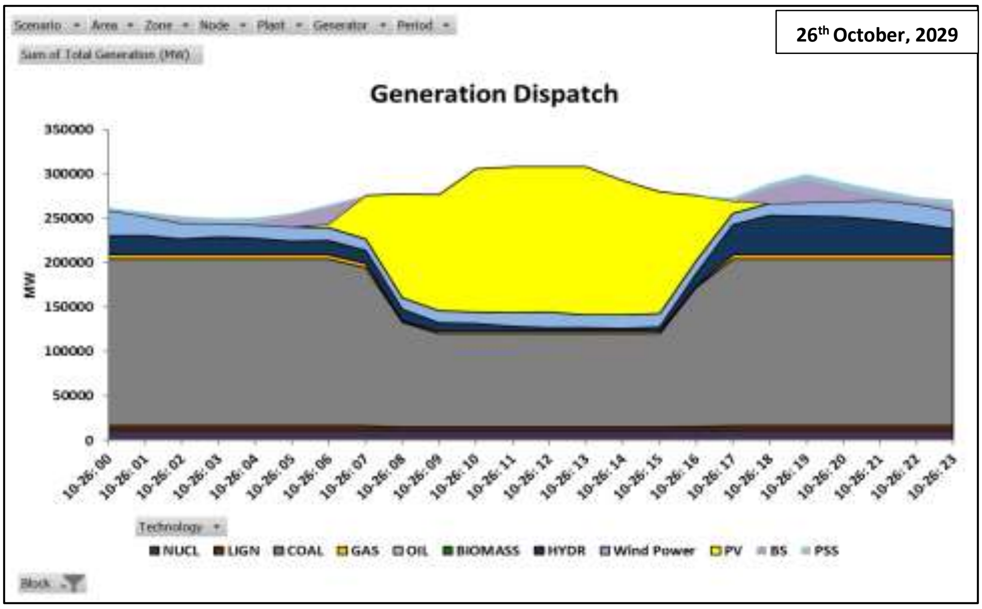
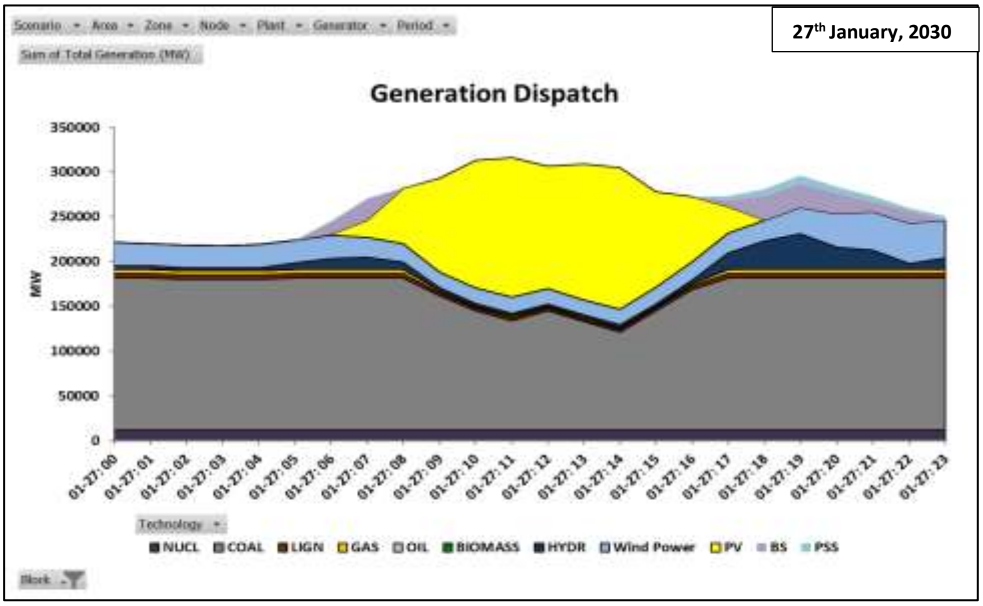
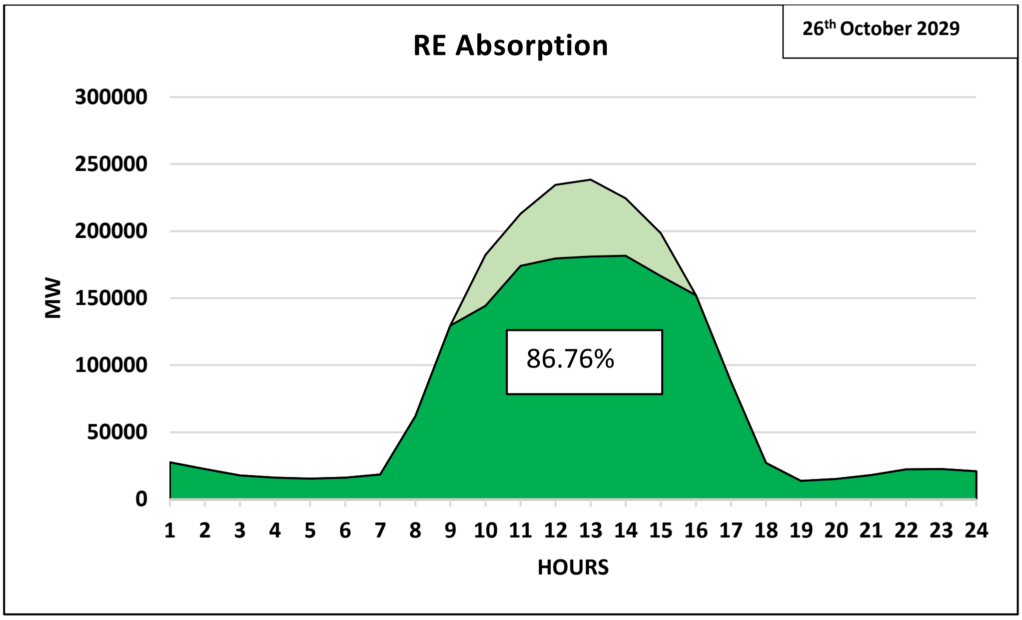



**Exhibit 24**



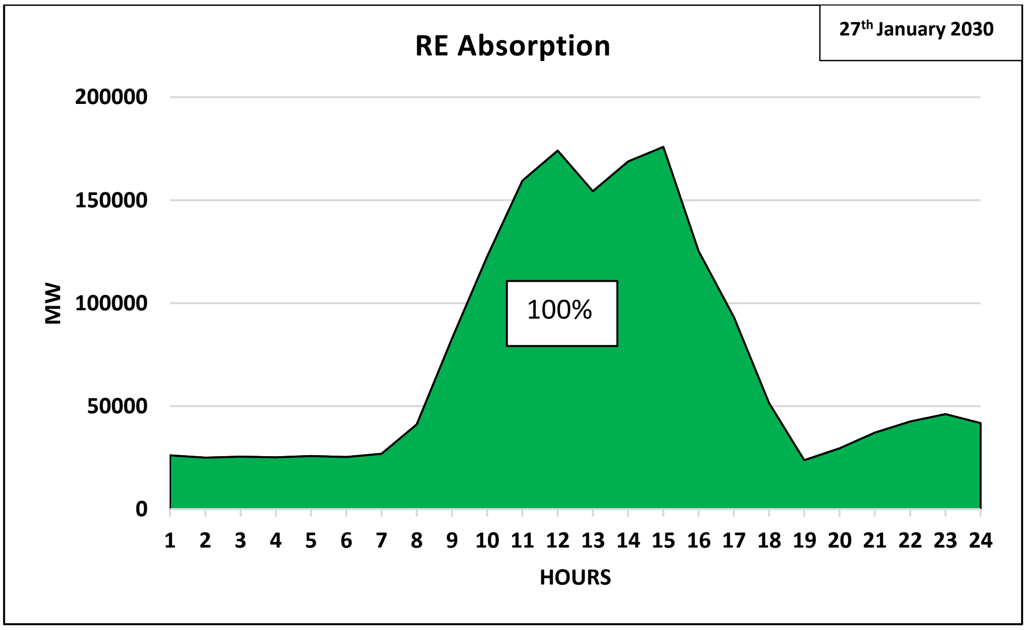

It has been observed that on this day (26th October) the demand is relatively higher and thus the coal-based capacity for the day is also high to meet the evening peak. Due to this, the RE generation could not be fully absorbed in the grid and the likely RE absorption on this day is about 86.76% as shown in **Exhibit 25**.

**Exhibit 25**




On 27th January the wind generation available is significantly lower and solar generation is also low. On this day the RE generation could be fully absorbed in the grid. The RE absorption is shown in the **Exhibit 26**.

**Exhibit 26**



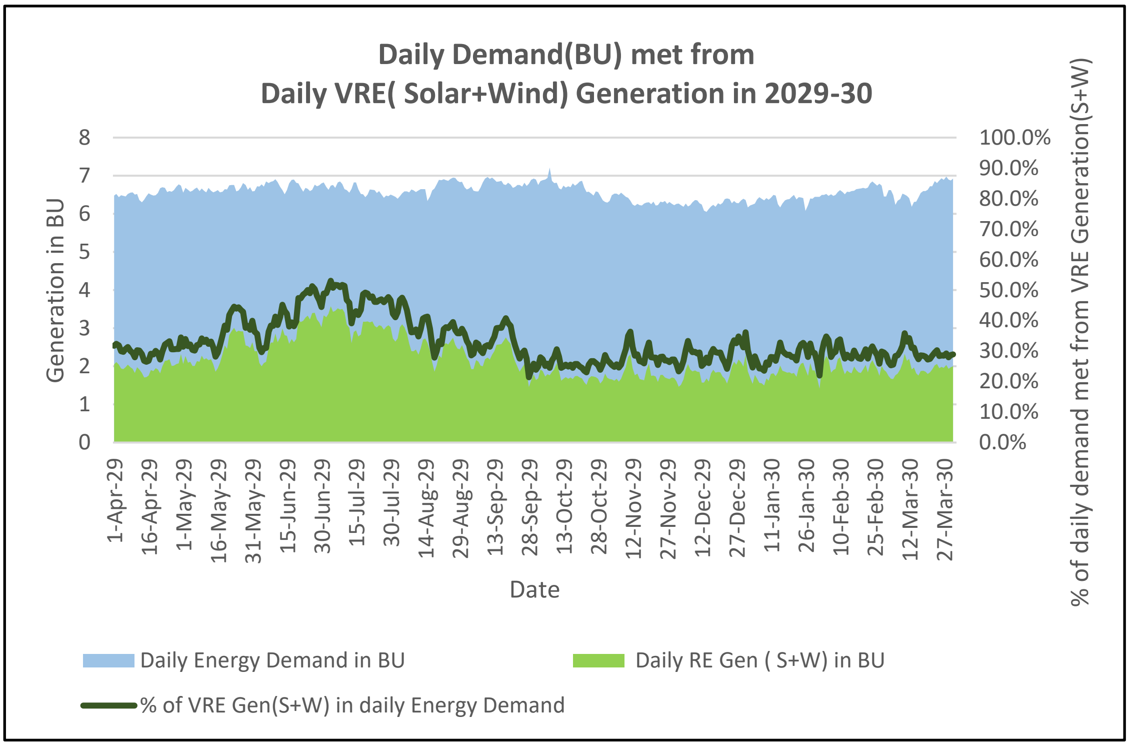
### 8.3.3 Analysis based on Short-term dispatch for 2029-30

The hourly economic dispatch has been studied for 8760 hours of the year 2029-30. Based on the analysis of the short-term hourly dispatch, following observations can be made:

#### 8.3.3.1 Daily Variation in Demand and VRE Absorption

The **Exhibit 27** 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 demand met by VRE generation on few days is as high as 50%.

**Exhibit 27**

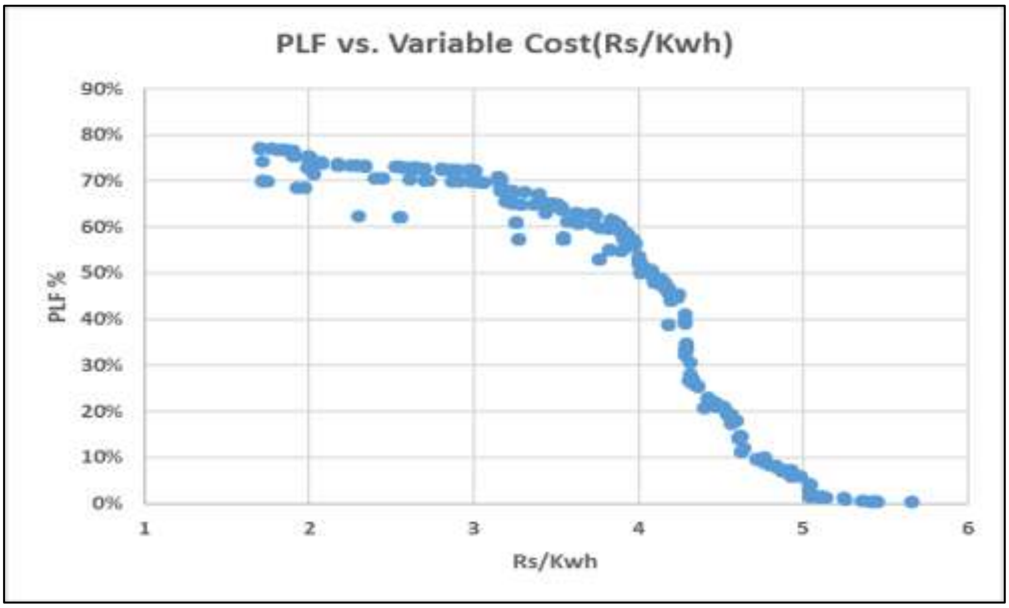



#### *8.3.3.2 Performance Analysis of Thermal Units*

#### A. Cost v/s PLF

The **Exhibit 28** 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.

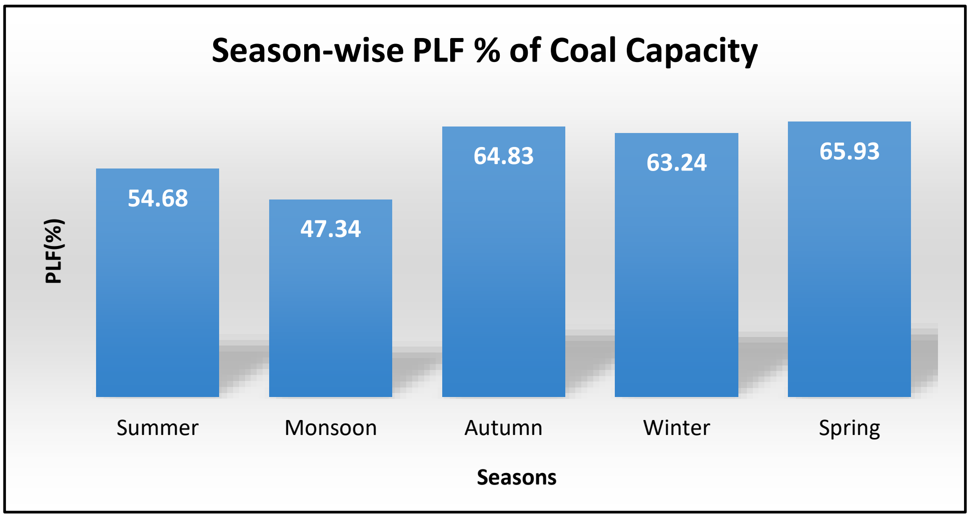
**Exhibit 28**




## B. Season-wise PLFs of coal capacity

Season-wise PLF of coal capacity has been analyzed and is shown in the **Exhibit 29** below.

**Exhibit 29**

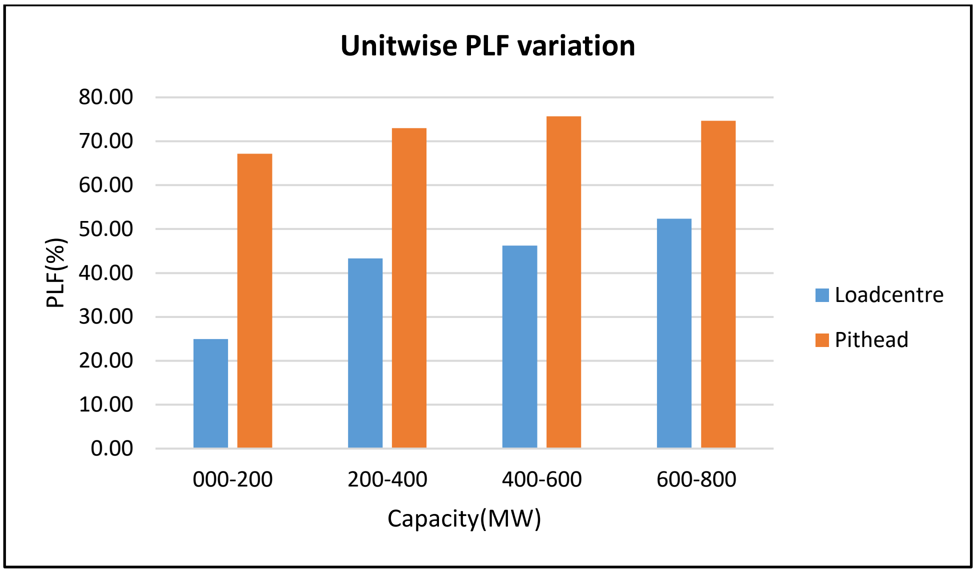



The chart shown above indicates that the lowest PLF of coal plants is expected to be in the monsoon season when Hydro and Wind Generation increases significantly. Coal generators can optimally schedule their annual maintenance during this season.

## C. Unit-wise PLF variation

The **Exhibit 30** shown below depicts the variation in the PLFs of load centred versus Pit head coal units and also reflects variation in PLFs depending on unit size.

**Exhibit 30**

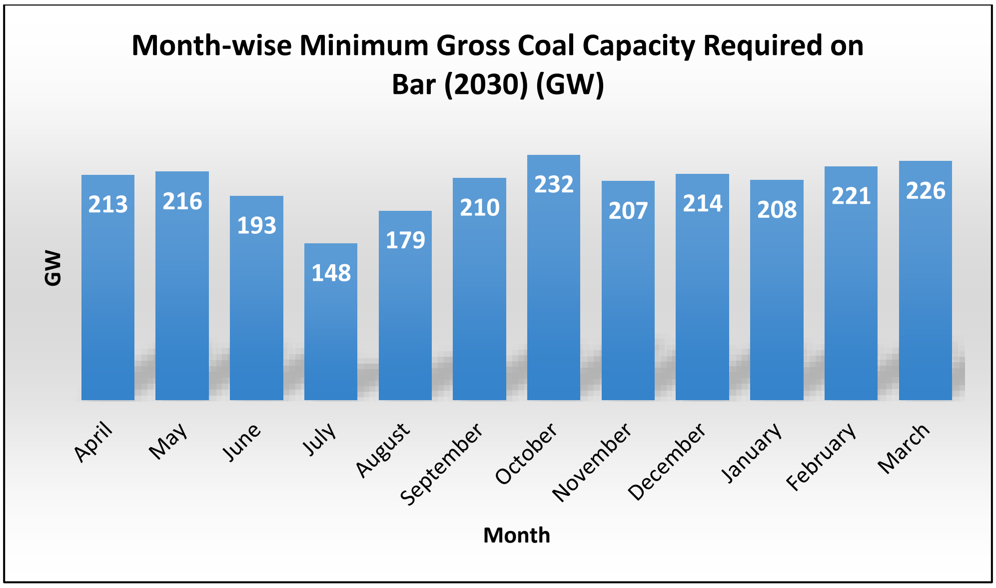



From the graph, it can be concluded that the load centre small size units may be required to run at low PLF of about 20% . Small sized units may be required to undergo flexible operation frequently compared to pit head large sized units.

## D. Coal capacity required on Bar

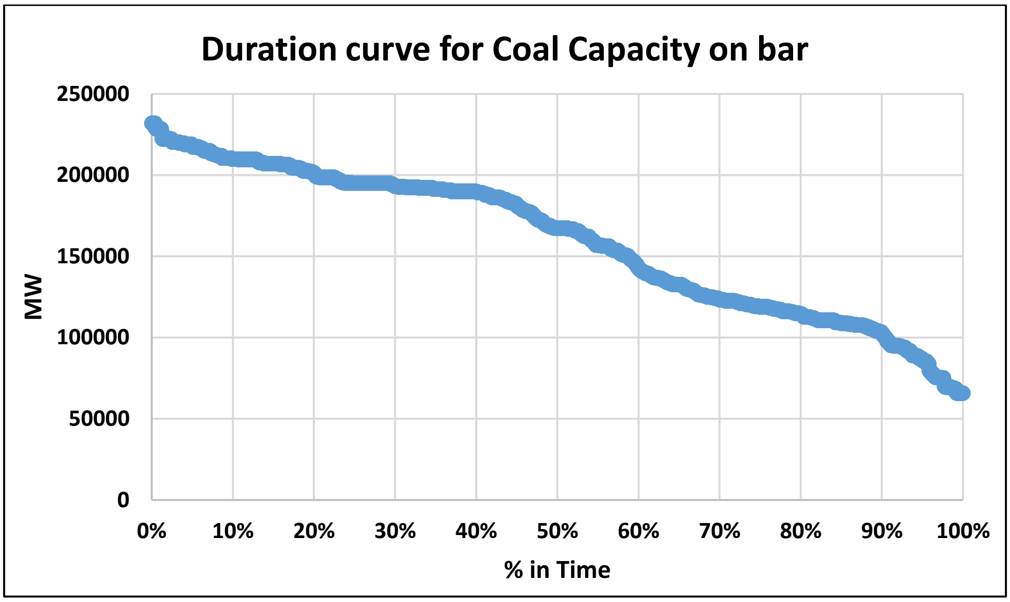
The **Exhibit 31** given below depicts the minimum Gross coal capacity required on grid to ensure capacity adequacy for meeting energy and peak requirement during the month.

**Exhibit 31**




It can be seen from the **Exhibit 32** 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 32**




Some of the salient outcomes of the short term dispatch in respect of coal based capacity are as follows:

- The maximum coal capacity (Gross) required on bar was found to be about 232 GW in the month of October.
- The average PLF of the total Installed coal capacity of 266.9 GW was found to be about 58% in 2029-30.
- Coal based capacity of about 32 GW is expected to run at low PLF of less than 30% while a capacity of 127 GW is expected to run at high PLF of more than 70%.
- About 55% of the total coal capacity is expected to record a PLF of more than 65% for the whole year.

## 8.4 Study on impact of reducing minimum technical load of coal plants on VRE absorption

The extent of RE absorption in the system depends on factors like operational constraints of coal based power plants , availability of flexible sources of power generation, RE generation profile, energy storage capabilities, demand profile etc.

From the studies, it is estimated that the annual RE absorption may be around 95% in the year 2029-30 mainly due to minimum technical load of coal plants, less flexibility in operation of Nuclear power plants and low availability of Domestic Gas etc.

It has been observed that the day to day variation of RE absorption varies between 83 % to 100%. The RE absorption for the critical days are shown in the **Table 7**.

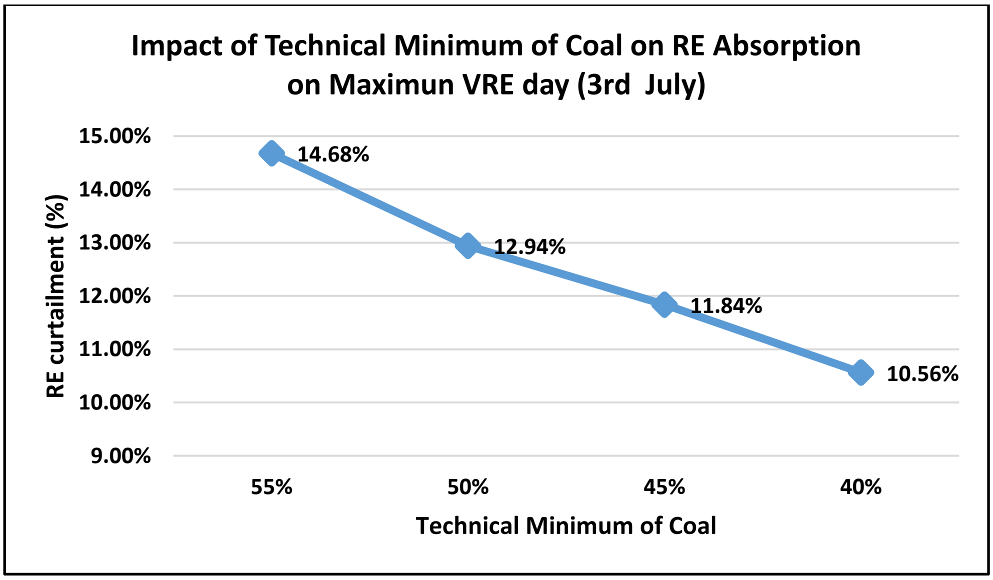
## Table 7

## RE Absorption on critical days

| Sl. No. | Scenario | Day | RE absorption |
|---|---|---|---|
| 1 | Peak Day / Max Energy demand day | 7th October, 2029 | 99.74 % |
| 2 | Maximum VRE (Wind+Solar) generation day | 3rd July, 2029 | 85.32 % |
| 3 | Maximum Solar generation day | 25th March, 2030 | 89.56 % |
| 4 | Minimum Solar generation day | 8th August, 2029 | 100% |
| 5 | Minimum Energy demand day | 14th December, 2029 | 97.19 % |
| 6 | Minimum VRE (Wind+Solar) generation day | 1st February, 2030 | 100% |
| 7 | Maximum Variation in demand day | 27th January, 2030 | 100% |
| 8 | Maximum Variation in Net demand day | 26th October, 2029 | 86.76 % |

It has been observed that the RE absorption is around 85.32 % on 3rd July, 2029 (i.e. the Maximum VRE day). In order to study the impact of lowering the minimum technical load of coal based plants on RE absorption, a study has been carried out by reducing the minimum technical load of coal plants from 55% to 50%, 45% and 40% on this day. The impact of reducing minimum technical load on RE absorption on Maximum VRE day is shown in the **Exhibit 33**.

## Exhibit 33




During the course of above analysis, it was observed that RE absorption can be increased with reduction in minimum technical load, thus increasing flexible operation of thermal power plants. However, this entails investment for technological upgradation in coal based power plants. An increase of approximately 1.5 % in the RE absorption was observed for every step of 5

% reduction in minimum technical load of coal based capacity on this day. However, the impact on RE absorption by reducing minimum technical load of coal based plants may vary from day to day depending on the coal based capacity on bar and available RE generation.

### 8.5 Impact on $CO_2$ emission due to part load operation of coal based power plant

The efficiency of coal based power plant varies with the loading of the machine. The impact on efficiency due to part load operation is more in sub critical power plants than in the super critical coal based power plants. The efficiency for different loading conditions have been modelled in the studies. A study has been carried out to estimate impact of part load operation of coal based power plants due to high RE penetration in the system and shape of the demand curve.

A study of typical days, i.e. 7$^{th}$ October (peak demand day) and 3$^{rd}$ July (maximum VRE generation day) have been carried out by considering no efficiency drop vis-a-vis efficiency drop due to part load operation. It is observed that $CO_2$ emissions may increase to the tune of 1.3% due to efficiency drop on part load operation of coal based power plant on 7$^{th}$ October and 1.2% on 3$^{rd}$ July.

## 9. International Commitment - INDC Targets

In October 2015, India had submitted its Intended Nationally Determined Contribution (INDC) to UNFCCC. The key elements are:

- To reduce the emissions intensity of its GDP by 33% to 35% by 2030 from 2005 level.
- To achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030, with the help of transfer of technology and low cost international finance including from Green Climate Fund (GCF).
- To create an additional carbon sink of 2.5 to 3 billion tones of $CO_2$ equivalent through additional forest and tree cover by 2030.

## 10. Projected Achievements of INDCs by 2030

### 10.1 Installed capacity and share of non-fossil fuel

In March 2019, percentage of non- fossil fuel in installed capacity was 36.5 %. Studies for the year 2029-30 shows that it is likely to increase to 64% in March 2030. However, as per INDC target, the percentage of non- fossil fuel in installed capacity is to be 40% by 2030. **Table 8** give the percentage of non-fossil installed capacity by the end of 2029-30.

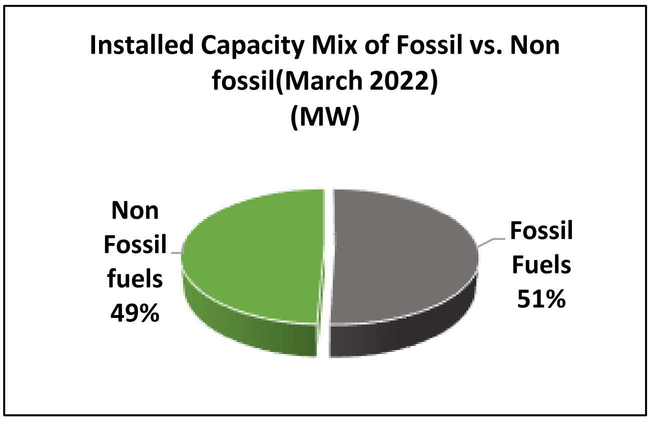
**Table 8**

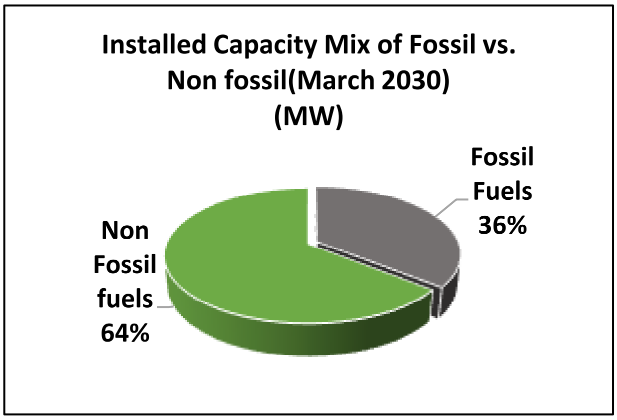
**Likely Installed Capacity mix of Fossil and Non-fossil* fuels**

| 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,2030** | 8,17,254 | 2,91,991 | 5,25,263 | 64% |

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

**Exhibit 34**




## 10.2 $CO_2$ emissions from Power Sector by 2030

As per generation expansion planning studies, the $CO_2$ emissions from the power sector during the year 2029-30 is likely to be 1287 MT **(Table 9).**

**Table 9**

**Likely annual CO2 Emissions**

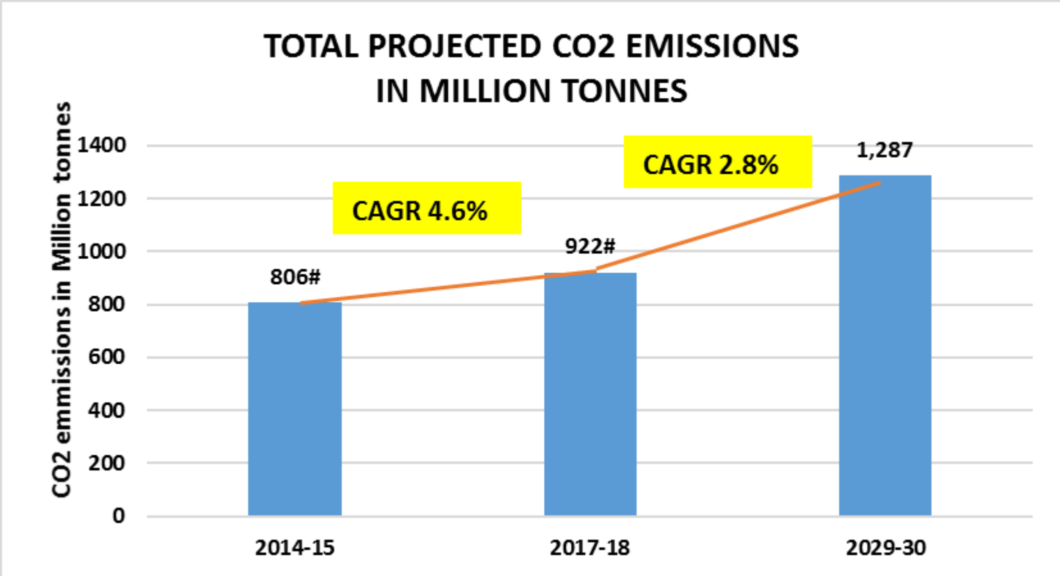
| | Year 2014-15# | Year 2017-18# | Year 2029-30 |
|---|---|---|---|
| **$CO_2$ Emissions Million Tonnes** | 806 | 922 | 1287* |

#Actual value as per CO2 baseline database of CEA

*Actual CO2 emissions may vary depending on the actual RE generation

The total CO2 emissions has increased from 806 Million tones in the year 2014-15 to 922 Million tones in the year 2017-18. As per the studies, CO2 Emissions from power sector are likely to increase to 1287 Million tones in the year 2029-30 as shown in **Exhibit 35**.

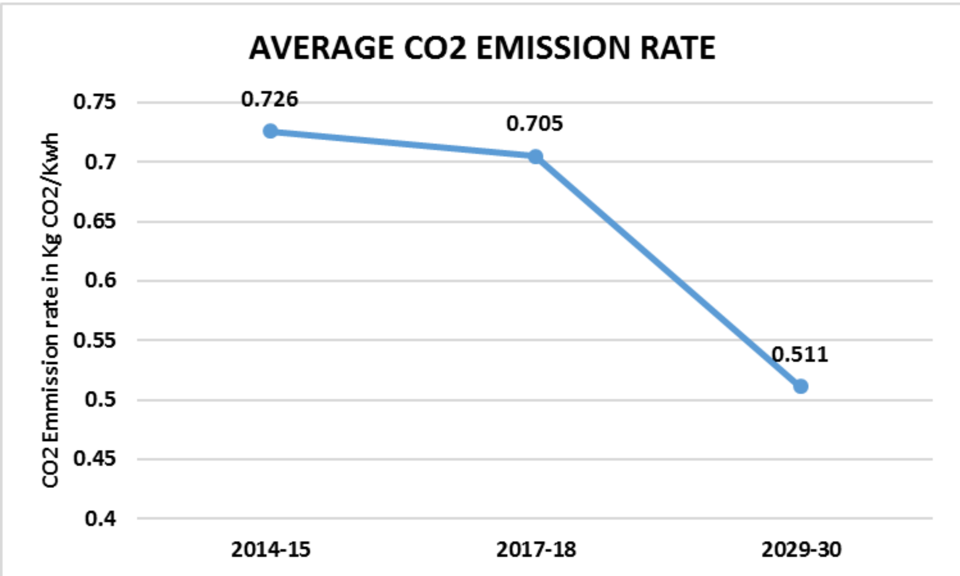
**Exhibit 35**




#Actual value as per CO2 baseline database of CEA

The average emission factor $kgCO_2/kWh$ from the total generation including renewable energy sources in base case scenario has been estimated and are shown in **Exhibit 36**. The average emission factor is likely to reduce to 0.511 kgCo2/kWh by the year 2029-30 from 0.705 kg/kWh in the year 2017-18.

**Exhibit 36**



### 10.3 Projected Coal Requirement in 2029-30

The Gross Generation from coal power plant is estimated to be 1358 BU for the year 2029-30. The coal requirement for the year 2029-30 has been worked out to be about 892 Million Tonnes considering specific coal consumption of 0.65kg/kWh + 1% transportation loss.

# 11. Sensitivity Analysis

While carrying out the planning studies for the future, there is likelihood of many uncertainties. To address the uncertainties and to test the resilience of the planned generation capacity mix for the extreme eventualities, sensitivity analysis has been carried out apart from the studies for critical days. Hydro and RE generation is highly weather dependent and may vary during season to season. There may be a possibility that the solar and wind generation on the peak demand day may not be as expected. There could be a possibility that the available generation from hydro may come down due to drought conditions. Therefore, hourly generation dispatch studies for following unexpected events has been carried out.

- 10% reduction in solar and wind generation during the week (4th Oct to 10th Oct 2029) having All-India peak demand day i.e. 7th Oct.
- 10% reduction in solar and wind generation during the week (1st Feb to 7th Feb 2030) having minimum solar and wind generation day i.e. 1st Feb.
- 6% reduction in hydro generation during the week (4th Oct to 10th Oct 2029) having All-India peak demand day i.e. 7th Oct.
- 10% reduction in RE generation and 6% reduction hydro generation combined together during the week (4th Oct to 10th Oct 2029) having All-India peak demand day i.e. 7th Oct.

## 11.1 10% reduction in Solar and Wind generation during the week having All-India peak demand day i.e. 7th Oct

The week containing the day on which the peak demand occurs i.e. 7th October has been studied in detail for the eventuality of 10% reduction in solar and wind generation. It has been observed that on the day when the peak demand is maximum, even if the variable RE (wind & solar) generation is reduced by 10% during the week, the demand is likely to be fully met with the generation capacity mix as per the long term studies and RE generation may be fully absorbed.

Generation dispatch on the day is shown in the **Exhibit 37**. RE generation dispatch and absorption is shown in **Exhibit 38**.

**Exhibit 37**

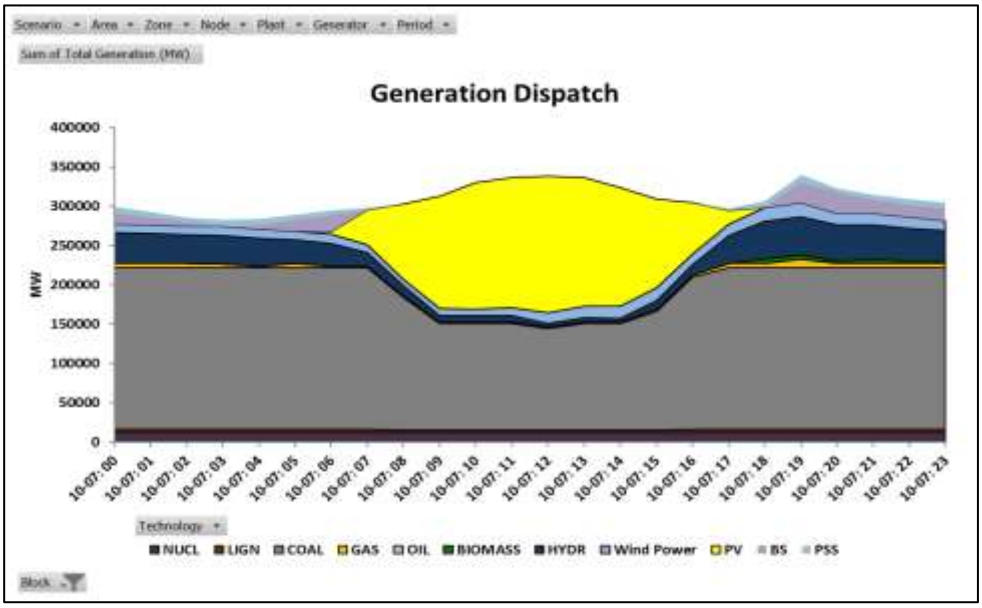
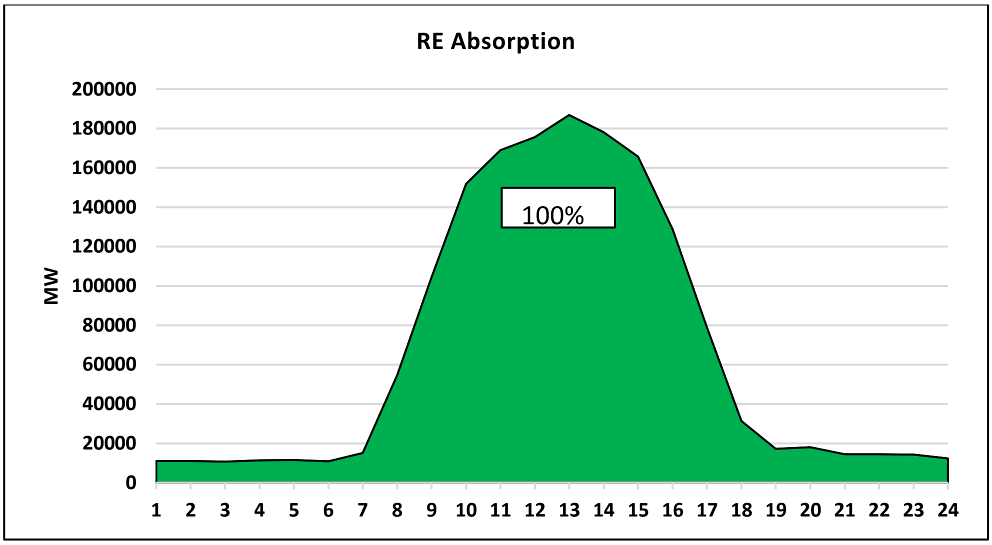



**Exhibit 38**




## 11.2 10% reduction in Solar and Wind generation during the week having minimum solar and wind generation day i.e. 1st Feb

The week containing the day on which the minimum RE generation is observed i.e. 1st February has been studied in detail for the eventuality of 10% reduction in solar and wind generation. It has been observed that on this day the demand is likely to be fully met with the capacity mix as per the long term studies. RE generation may be fully absorbed on this day.

Generation dispatch on the day is shown in the **Exhibit 39**. RE generation dispatch and absorption is shown in **Exhibit 40**.

**Exhibit 39**

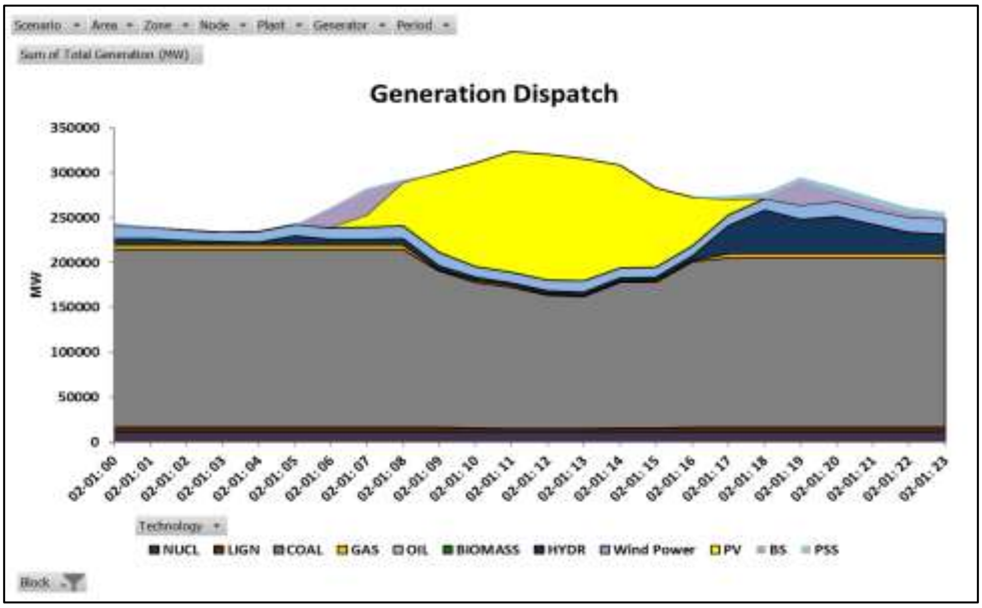
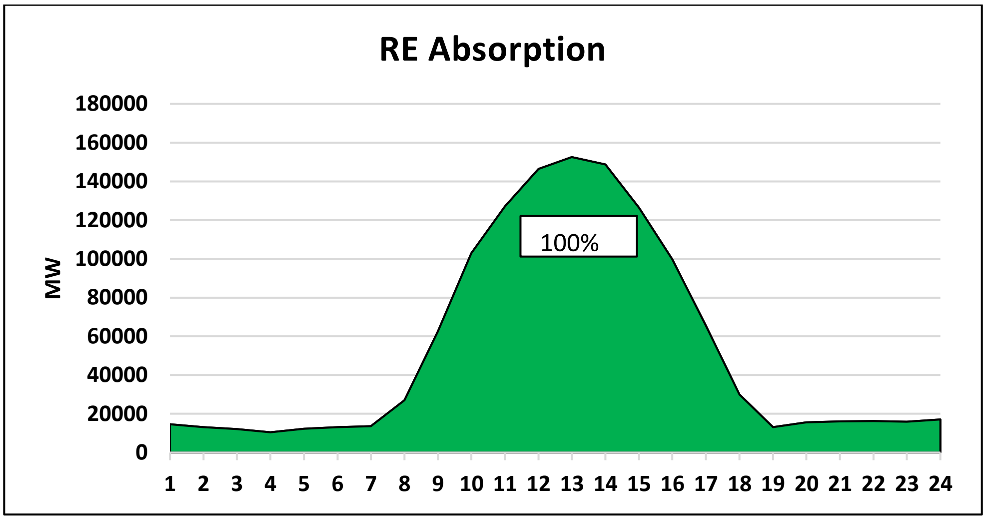



**Exhibit 40**

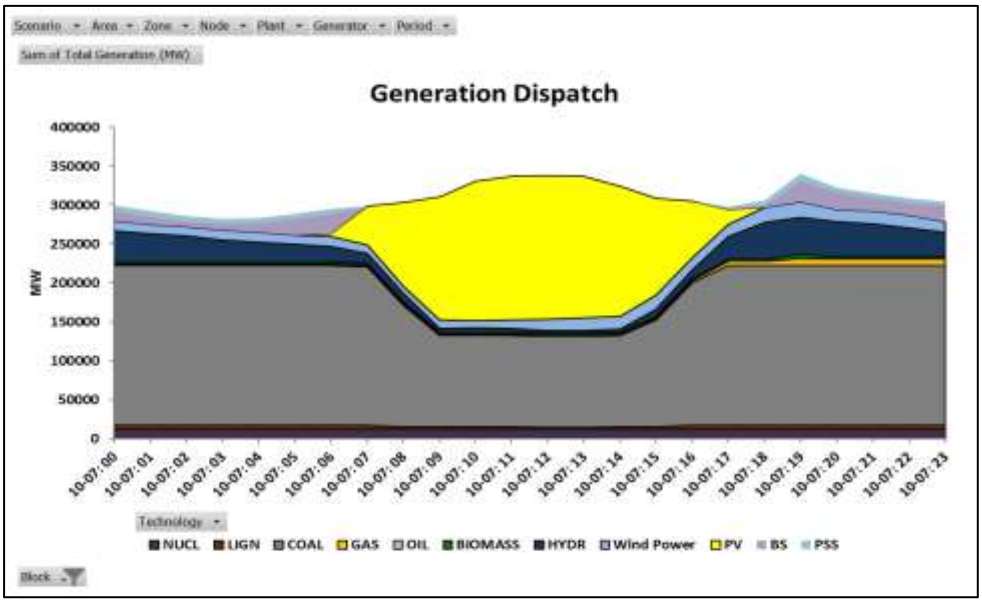



## 11.3 6% reduction in hydro generation during the week having All-India peak demand day i.e. 7th Oct

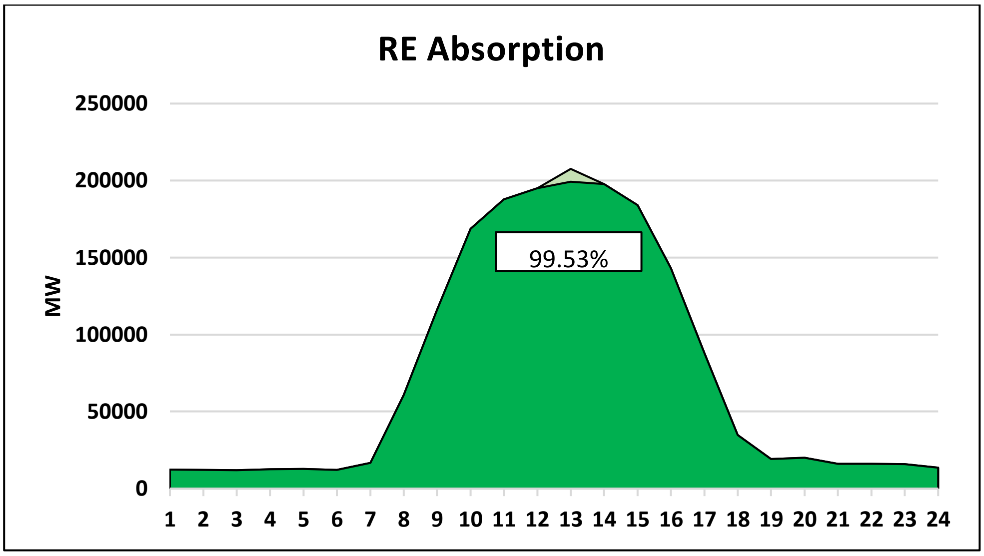
The hydro generation varies on year to year basis depending on the rainfall pattern. Analyzing the past data of hydro generation, it has been observed that in a drought year, there may be a 6% reduction in the generation from hydro plants. Therefore, the week containing the day on which the peak demand occurs, 7th October has been studied in detail for the eventuality of 6% reduction in available hydro generation (drought in year 2029-30). Generation dispatch on the day is shown in the **Exhibit 41**.

It has been observed that on the day when the peak electricity demand is maximum, if the hydro generation is reduced by 6%, the demand is fully met during the day with the capacity mix as per the long term studies. It is however observed that the generation from RE sources may not be fully absorbed. The RE Absorption on this day is likely to be around 99.53%. RE generation dispatch is shown in the **Exhibit 42**.

## Exhibit 41




## Exhibit 42

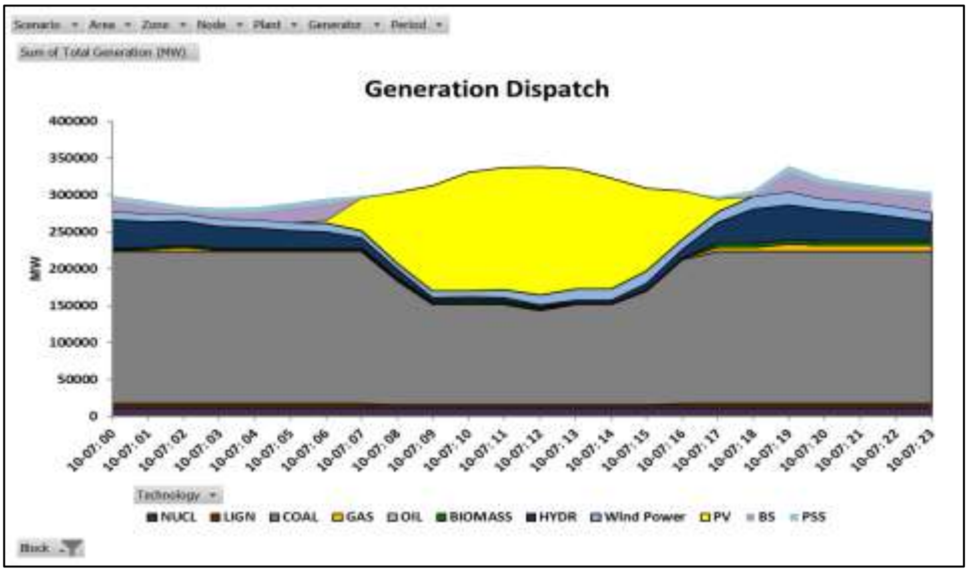


## 11.4 10% reduction in RE generation and 6% reduction hydro generation combined together during the week having All-India peak demand day i.e. 7th Oct

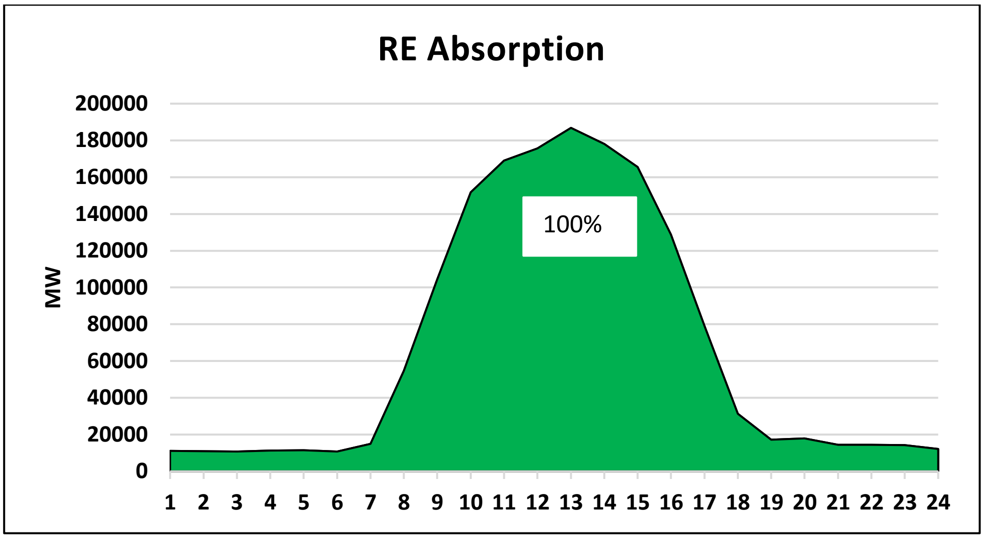
The extreme eventuality of a drought year (6% less hydro generation) combined with reduced variable RE (solar and wind) generation (10% reduced RE generation) has been studied as a sensitivity case. However, it is felt that this situation may not arise. It has been observed that on the day when the peak demand is maximum, if the hydro generation is reduced by 6% and RE generation is reduced by 10% for the week having the peak demand, the demand may not be fully met with the capacity mix as per the long term studies and unserved energy may be observed during few hours. However, if the availability of the coal based capacity is increased by 0.5%, the demand can be fully met. Generation dispatch on the peak day with this sensitivity is shown in the **Exhibit 43**.

The generation from RE sources may be fully absorbed. RE generation dispatch after increasing the coal capacity availability and resulting absorption is shown in the **Exhibit 44**.

**Exhibit 43**



## Exhibit 44


RE Absorption
MW
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
100%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

# 12. Additional Scenario Analysis

To study the impact of uncertainties associated with various assumptions like variations in energy demand forecast, capital cost associated with various generation technologies etc., following additional scenarios have been studied:

i) Electricity Demand variation of +/- 5% from base case
ii) Increase in the basic battery cost projections to $100/kWh and $125/kWh by 2030 from $75/kWh considered in base case.

## 12.1 Electricity Demand variation of +/- 5% from base case.

The annual energy requirement in the base study has been considered as 2400 BU with peak demand of 340 GW.

### 12.1.1 Increase in Demand by 5% from base case demand.

A scenario with 5% increase in projected electrical energy demand i.e. 2516 BU with peak demand remaining same as 340 GW in 2029-30 has been considered. The results of likely installed capacity are given in **Table 10** below.

**Table 10**

**Likely Installed capacity by the end of 2029-30**

| Fuel Type | Capacity (MW) in 2029-30 | Percentage Mix (%) |
|---|---|---|
| Hydro * | 61,657 | 7.35% |
| PSP | 10,151 | 1.21% |
| Small Hydro | 5,000 | 0.60% |
| Coal + Lignite | 2,68,511 | 32.01% |
| Gas | 25,080 | 2.99% |
| Nuclear | 18,980 | 2.26% |
| Solar | 2,99,404 | 35.70% |
| Wind | 1,40,000 | 16.69% |
| Biomass | 10,000 | 1.19% |
| **Total** | **8,38,783** | |
| Battery Energy Storage | 25,122MW/100,488MWh | |
| *Including Hydro Imports of 5856MW | | |

With increase in electrical energy demand only (no change in peak demand), load factor of the capacities may increase and performance of Thermal power plants is likely to improve. The results have shown that there may be higher installed capacity of solar with marginal uptick from Hydro and Coal installed capacities.

### 12.1.2 Decrease in Demand by 5% from base case demand.

A scenario with 5% reduction in projected electrical energy demand i.e. 2284 BU with peak demand remaining same as 340 GW in 2029-30 has been considered. The results of likely installed capacity are given in **Table 11** below.

**Table 11**

**Likely Installed capacity by the end of 2029-30**

| Fuel Type | Capacity (MW) in 2029-30 | Percentage Mix (%) |
|---|---|---|
| Hydro * | 60,737 | 7.64% |
| PSP | 10,151 | 1.28% |
| Small Hydro | 5,000 | 0.63% |
| Coal + Lignite | 2,66,111 | 33.46% |
| Gas | 25,080 | 3.15% |
| Nuclear | 18,980 | 2.39% |
| Solar | 2,59,165 | 32.59% |
| Wind | 1,40,000 | 17.61% |
| Biomass | 10,000 | 1.26% |
| **Total** | **7,95,224** | |
| Battery Energy Storage | 27,728 MW/83,184MWh | |
| *Including Hydro Imports of 5856MW | | |

With decrease in electrical energy demand only (no change in peak demand), load factor of the thermal capacities may decrease. The results have shown that there may be lower installed capacity of solar with marginal downtick from Hydro and Coal installed capacities as compared to base case scenario. However, to meet the peak demand , BESS inverter size is slightly increased but a battery storage of 3 hours ie 83,184 MWh is likely be sufficient.

## 12.2 Increase in the battery cost projections by 2030 to $100/kWh and $125/kWh.

The cost trajectory for battery energy storage system (BESS) is assumed to be reducing uniformly from ₹ 7 Cr in 2021-22 to ₹ 4.3 Cr (with basic battery cost of $75/kWh) in 2029-30 for a 4 hour battery system in the base case study. However, there are several uncertainties associated influencing this cost trend like currency fluctuations, trade limitations, raw material availability etc. Therefore, additional scenarios with higher battery cost (basic battery cost of $100/kWh and $125/kWh) compared to the base case study have been analyzed.

### 12.2.1 Increase in the battery cost projections by 2030 to $100/kWh

The results of likely installed capacity in this scenario are given in **Table 12** below.

**Table12**

**Likely Installed capacity by the end of 2029-30**

| Fuel Type | Capacity (MW) in 2029-30 | Percentage Mix (%) |
|---|---|---|
| Hydro * | 61,657 | 7.51% |
| PSP | 11,151 | 1.36% |
| Small Hydro | 5,000 | 0.61% |
| Coal + Lignite | 2,70,111 | 32.88% |
| Gas | 25,080 | 3.05% |
| Nuclear | 18,980 | 2.31% |
| Solar | 2,79,550 | 34.03% |
| Wind | 1,40,000 | 17.04% |
| Biomass | 10,000 | 1.22% |
| **Total** | **8,21,529** | |
| Battery Energy Storage | 22,970 MW/91,880 MWh | |
| *Including Hydro Imports of 5856MW | | |

### 12.2.2 Increase in the battery cost projections by 2030 to $125/kWh

The result of likely installed capacity in this scenario is given in **Table 13** below.

**Table13**

**Likely Installed capacity by the end of 2029-30**

| Fuel Type | Capacity (MW) in 2029-30 | Percentage Mix (%) |
|---|---|---|
| Hydro * | 61,657 | 7.56% |
| PSP | 11,151 | 1.37% |
| Small Hydro | 5,000 | 0.61% |
| Coal + Lignite | 2,80,511 | 34.37% |
| Gas | 25,080 | 3.07% |
| Nuclear | 18,980 | 2.33% |
| Solar | 2,63,775 | 32.32% |
| Wind | 1,40,000 | 17.15% |
| Biomass | 10,000 | 1.23% |
| **Total** | **8,16,154** | |
| Battery Energy Storage | 14,670 MW/58,680 MWh | |
| *Including Hydro Imports of 5856MW | | |

# 13.0 Conclusions

The long term study results for the period 2022-23 to 2029-30 is the least cost generation mix and most economical solution for meeting the peak electricity demand and electrical energy requirement of each year till 2029-30 as projected by 19th EPS. The capacity mix honours all the technical constraints associated with various technologies. Grid scale Battery energy storage systems(BESS) along with Pumped Storage systems has been considered for estimating the optimal results keeping in view the challenge of RE integration due to its inherent nature of being variable and intermittent and to fulfil the demand at every instance of time.

The installed capacity by the end of 2029-30 projected is 8,17,254 MW comprising of Hydro 60,977 MW ( including Hydro Imports 5,856 MW), PSP 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. With this installed capacity, the INDC target set for India i.e. the percentage of non- fossil fuel capacity in the total installed capacity is to be 40% by 2030 is likely to be met.

The projected gross electricity generation (BU) during the year 2029-30 is likely to be 2,518 BU comprising of 1,393 BU from Thermal (Coal, Gas and Lignite), 801 BU from RE Sources, 207 BU from Hydro, 4.4 BU from PSS and 113 BU from Nuclear. It is estimated that non-fossil fuels generation contribution is likely to be around 44.7% of the gross electricity generation during the year 2029-30.

It may be noted that with further increase in capacity addition from other environmental friendly energy storage system like PSPs, BESS capacity requirement in the year 2029-30 may reduce.

The economic hourly dispatch of generation capacity mix for the year 2029-30 have been studied for critical days like maximum peak demand day, maximum energy demand day, maximum/minimum variable RE generation day, maximum/minimum solar energy generation day, minimum energy demand day, day with maximum variation in demand/net demand. It is found that the energy requirement at every instance of time has been met with all the technical/operational constraints. It was observed that the RE generation which could not be absorbed in the system on a day-to-day basis is in the range of 0% (on minimum RE generation day) to 14.6% (on maximum RE generation day). 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.

In order to study the impact on increase in RE absorption by lowering the minimum technical load of coal based plants, a study has also been carried out by reducing the minimum technical load of coal based plants from 55% to 50%, 45% and 40% on maximum solar generation day. It has been found that the RE absorption gradually increases with decreasing the minimum technical load of operation. However, the RE absorption may vary depending upon the coal based capacity on bar and available RE generation.

The average PLF of the total Installed coal capacity of 267 GW is projected to be about 58% in 2029-30. The coal requirement for the year 2029-30 has been worked out to be about 892 MT considering specific coal consumption of 0.65kg/Kwh + 1% transportation loss.

Sensitivity analysis for contingency scenarios have been carried out during the week of $7^{th}$ October, 2029. The results of the sensitivity studies show that with the base case installed capacity along with a battery energy storage capacity of there may not be unserved energy at any instance of time even if projected generation from RE sources are reduced by 10% or hydro generation by 6% due to drought conditions. However, with simultaneous reduction in RE energy by 10% and Hydro energy by 6%, availability of coal-based units may be needed to be increased by 0.5% to meet energy demand at all instances of time.

Further, the impact on efficiency due to part load operation and $CO_2$ emissions from coal-based power plant has been studied for the peak demand day i.e. $7^{th}$ Oct, 2029 and maximum RE generation day i.e. $3^{rd}$ July 2029. It is observed that $CO_2$ emissions may increase to the tune of 1.2% on $3^{rd}$ July 2029 due to efficiency drop on account of part load operation of coal based power plant. The $CO_2$ emissions for the year 2029-30 has been studied and the study results show that $CO_2$ emissions from the Power Sector is likely to be 1287 MT. The average CO2 emission rate is likely decrease from 0.726 kg/kWh in 2014-15 to 0.511 kg/kWh in the year 2029-30

Additional scenarios have also been incorporated in the final studies in view of possible variations in ± 5% Energy Demand and considering higher Battery cost projections for the year 2029-30.

# ANNEXURE

**Annexure-I/1**

## ASSUMPTIONS

**A. Likely installed capacity by 2021-22 as per Mid-Term Review of NEP (Base Capacity considered):**

| Technology | Capacity(MW) |
|---|---|
| Hydro* | 44,989 |
| Pumped Storage | 5246 |
| Coal | 2,15,773 |
| Gas | 25,343 |
| Nuclear | 10,080 |
| Solar | 1,00,000 |
| Wind | 60,000 |
| Biomass | 10,000 |
| Small Hydro | 5,000 |
| **Total IC by 2021-22** | **4,76,431** |

*Excluding hydro imports of 2136 MW

**B. Under construction, Planned and Candidate plants considered in the study for the period 2022-23 to 2029-30:**

| Technology | Additional Planned/Under construction capacity b/w 2022-23 & 2029-30 (MW) |
|---|---|
| Hydro | 6,494 |
| Hydro Imports | 3,720 |
| Coal (Pithead)<br>Coal (Load-centered) | 8,630 |
| Gas | 0 |
| Nuclear –LWR & PHWR | 8,900 |
| Solar | 0 |
| Wind | 0 |
| Biomass | 0 |
| Pumped Storage | 1705 |
| Battery Energy Storage | 0 |

**Annexure-I/2**

## C) COST PARAMETERS

Following cost parameters for candidate plants have been assumed in the year 2021-2022:

| Technology | Capex (in ₹/MW) | O&M Fixed Cost (in ₹/MW) | Construction Time (in years) | Amortization/Lifetime (in years) |
|---|---|---|---|---|
| Coal (Pithead)#1 | 7.85 Cr | 18 Lakh | 4 | 25 |
| Coal (Load centered) | 7.60 Cr | 18 Lakh | 4 | 25 |
| Nuclear (LWR) | 19 Cr | 20 Lakh | 6 | 30 |
| Nuclear (PHWR) | 11.70 Cr | 20 Lakh | 6 | 30 |
| Hydro#2 | 5.5 Cr to 28 Cr | 2.5% of Capex | 5 to 8 | 40 |
| Solar | 4.50 Cr | 1 % of Capex | 0.5 | 25 |
| Wind | 6 Cr | 1% of Capex | 1.5 | 25 |
| Biomass | 5.7 Cr | 2% of Capex | 3 | 20 |
| Pumped Storage | 2 Cr to 5.7 Cr | 2.5% of Capex | 8 | 40 |
| Battery Energy Storage | 7 Cr | 2% of Capex | 0.5 | 10 |

#1 Capex of pithead plants is ₹25 lakh higher than load centered due to the additional cost of construction of MGR arrangement for coal transport. Cost of flue gas desulphurization plant is included in the capital cost of Coal based power plants.

#2 Capital costs as per DPR available

## D) Other assumptions-

- All costs considered are with respect to the base year of the study i.e. 2021-22.
- Discount rate – 10.36 %
- Capital costs of solar plants uniformly reduced from ₹ 4.5 Cr/MW in 2021-22 to ₹ 4.1 Cr/MW during the year 2029-30.
- Cost of battery energy storage with 4 hour battery is taken as ₹ 7 Cr/MW (including cost of battery, inverter, EMS, BMS etc.) in 2021-22 and reduced uniformly to ₹ 4.3 Cr/MW in 2029-30.
- Cost of unserved energy – ₹ 20/kWh.
- No transmission constraints have been envisaged in the system.
- Fuel quota limitations on Gas availability to the present level of domestic gas supply to power sector.
- Nuclear plants to run at constant load.
- Biomass is limited to annual PLF of 30% due to seasonal fuel availability.
- A product escalation of 1 % per annum in cost of coal is assumed.

**Annexure-I/3**

## E) TECHNICAL PARAMETERS

| Technology | Type | Availability (%) | Ramping (%/min) | Min. Technical. (%) | Start -up time (hr) | | |
|---|---|---|---|---|---|---|---|
| | | | | | Hot | Warm | Cold |
| Coal | Existing/Planned | 75-87 | 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 | - | - | - | - |
| | Candidate | 68 | - | - | - | - | - |
| Biomass | Existing/Planned | 60 | 2 | 50 | 2 | 4 | 8 |
| | Candidate | 60 | 2 | 50 | 2 | 4 | 8 |
| Hydro | Existing/Planned/ Candidate | As per actual month energy | 100 | - | - | - | - |
| Solar | Existing/Planned | As per available hourly generation profile | - | - | - | - | - |
| | Candidate | | - | - | - | - | - |
| Wind | Existing/Planned | | - | - | - | - | - |
| | Candidate | | - | - | - | - | - |
| Pumped storage | Existing/Planned | As per the Project Report | 50 | - | - | - | - |
| | Candidate | | 50 | - | - | - | - |
| Battery Energy Storage | Candidate | 98 | NA | - | - | - | - |

| Technology | Type | Heat Rate* (MCal/MWh) | | Aux. Consum. (%) | Min. online time (hr) | Min. offline time (hr) | Start-up fuel consumption (MCal/MW) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | At max loading | At 55% loading | | | | Hot | Warm | Cold |
| Coal | Existing/ Planned | 2300 to 2879 | 2438 to 3052 | 7.0 | 6 | 4 | 600 | 1000 | 1800 |
| | Candidate (SC & USC) | 2060 to 2125 | 2183 to 2253 | 6.5 | 6 | 4 | 600 | 1000 | 1800 |
| Gas | Existing | 2000 to 2900 | 2260 to 3277 | 2.5 | 4 | 3 | 30 | 50 | 90 |
| Nuclear | Existing/ Planned | 2777 | 2777 | 10 | 6 | 4 | - | - | - |
| | Candidate | 2777 | 2777 | 10 | - | - | - | - | - |
| Biomass | Existing/ Planned | 4200 | 4450 | 8 | 6 | 4 | 600 | 1000 | 1800 |
| | Candidate | 4200 | 4450 | 8 | 6 | 4 | 600 | 1000 | 1800 |
| Hydro | Existing/ Planned | - | - | 0.7 | - | - | - | - | - |
| | Candidate | - | - | 0.7 | - | - | - | - | - |
| Pumped Storage | Existing/ Planned | - | - | pump efficiency 80 % | - | - | - | - | - |
| | Candidate | - | - | | - | - | - | - | - |
| Battery Energy Storage | Candidate | - | - | Round trip losses 12% | - | - | - | - | - |

* As per the available efficiency curve of heat rate vs loading

**Annexure-I/4**

## F) VARIABLE COSTS*

| Technology | Existing (₹/kWh) | Candidate (₹/kWh) |
|---|---|---|
| Coal | **1.51 to 4.66** | **1.63 to 2.65 (Pithead)<br>3.74 to 4.66 (load-centered)** |
| Lignite | **1.43 to 3.64** | **-** |
| Gas | **2.42 to 3.52** | **-** |
| Nuclear | **0.85** | **0.85** |
| Biomass | **7.73** | **7.73** |

*As in 2021/22