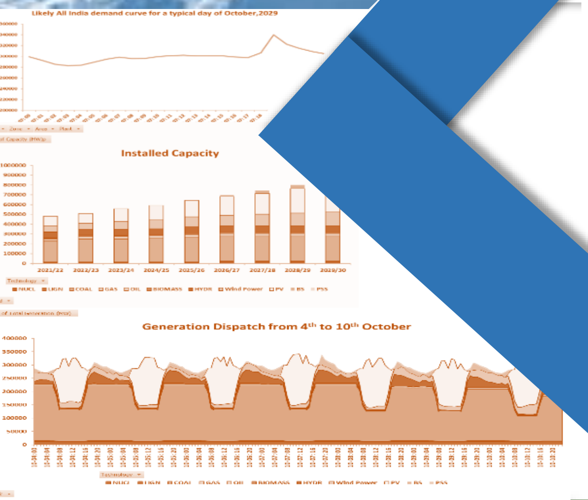

DRAFT REPORT ON OPTIMAL GENERATION CAPACITY MIX FOR 2029-30

FEBRUARY 2019

GOVERNMENT OF INDIA
MINISTRY OF POWER
CENTRAL ELECTRICITY AUTHORITY

सत्यमेव जयते

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Executive Summary

The world today is witnessing several kinds of technological disruptions in different sectors. One of the likely disruption can be replacement of thermal based generation with RE generation being 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 so as to render them financially viable. In this context, planning for optimal generation capacity mix gains tremendous importance so as the future generation capacity mix will be cost effective as well as environmental friendly. To achieve the mix, a horizon of 10-12 years is sufficient to gear up the systems and policies in the right direction. The study year 2029-30 has been considered keeping this in perspective.

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 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 constraints.

The base year of the study has been considered as 2021-22. The installed capacity projected in the National Electricity Plan (NEP) has been taken as input to find out the requirement of future generation capacity mix to be built up till 2029-30. The technical and financial parameters of different generation technologies have been considered as per National Electricity Plan.

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 critical days of the year 2029-30 have also 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. The study has also been carried out to assess the RE absorption by reducing presently stipulated technical minimum load of coal based plants.

Sensitivity analysis for contingency scenarios is also 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 is based on the assumption of a single demand node for the country and does not consider transmission lines in optimization.

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ACRONYMS

ACRONYMS	EXPANSION
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 Tonnes
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. The capacity addition has to be planned very optimally in view of the limited available fuel resources for generation and environmental concerns.

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 11th and 12th 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 also increased from 592 kWh during 2003-04 to 1149 kWh during 2017-18. 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 peak electricity demand and electrical energy requirement and supply gap is currently 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 60.67% during 2017-18 from 78.6% during 2007-08.

The world has started 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 also 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. The recent cost trends of RE generation sources have given them the footing to compete with conventional sources of electricity generation. 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. The cost of battery energy storage systems has been reducing at a fast pace with the technological advancement and the world is anticipating that it may help to absorb more RE into the power system in the foreseeable future.

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, Hydro including Pumped Storage, Nuclear, Natural gas.
- New & Renewable Energy Sources- Solar, Wind, Biomass, Small Hydro, etc.
- New Technologies – Grid scale battery energy storage systems.

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 also 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.

Also, 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 expected 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 pit head coal power plants which provide quite cheap energy. 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 so as the future generation capacity mix will be cost effective as well as environmental friendly. To achieve the mix, a horizon of 10-12 years is sufficient to gear up the systems and policies in the right direction. The study year 2029-30 has been considered keeping this in perspective.

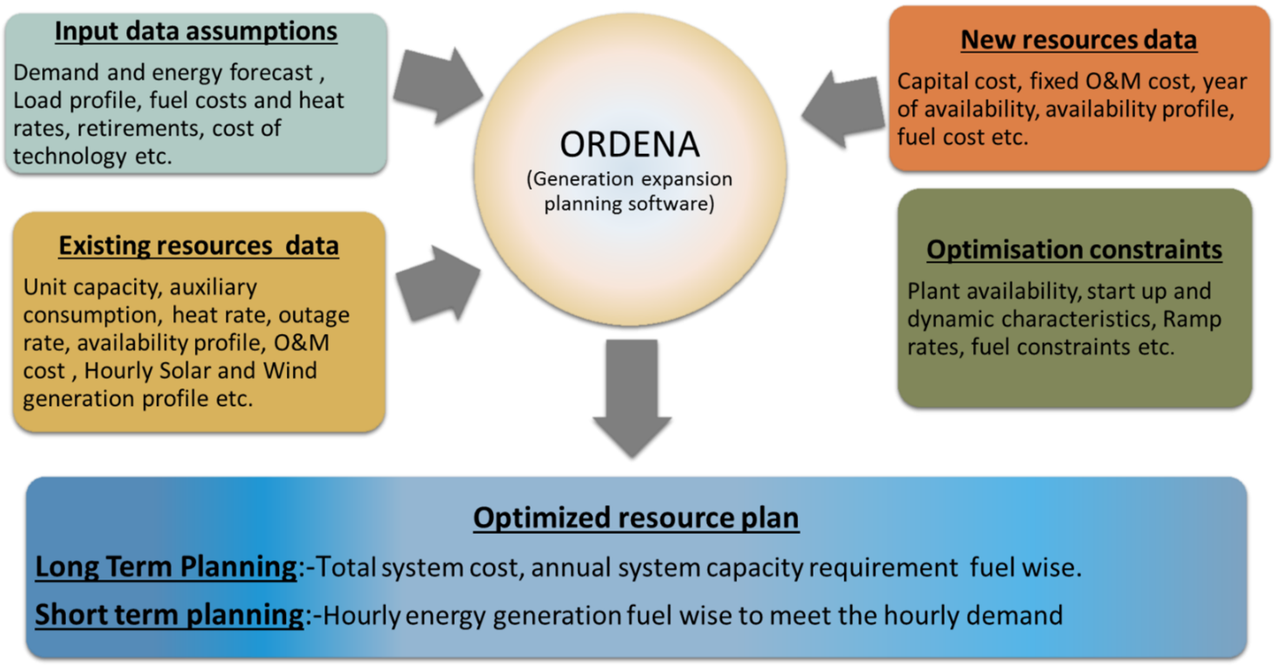
4. Generation Expansion Planning Tool

The optimal generation mix study for the year 2029-30 has been carried out with the latest state of the art computer planning model namely

ORDENA. The model performs generation expansion planning, production costing and also has the capability of modelling renewable energy sources. It also optimizes the cost of transportation of fuel and emissions from power plants. The model optimizes the least cost of energy generation including the capital investments required for meeting peak electricity demand and electrical energy requirement by carrying out various iterations for selecting the most optimal generation capacity mix including all financial parameters and satisfying technical/operational constraints. The software also has the capability to carry out 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 as on 31.01.2019 was 349.2 GW, which comprise of 45.4 GW from Hydro, 223 GW from Thermal, 74 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 31.01.2019 and energy contribution from different sources during 2018-19 till 31.12.2018 is given in **Table 1** and **Exhibit 2** respectively.

Table 1

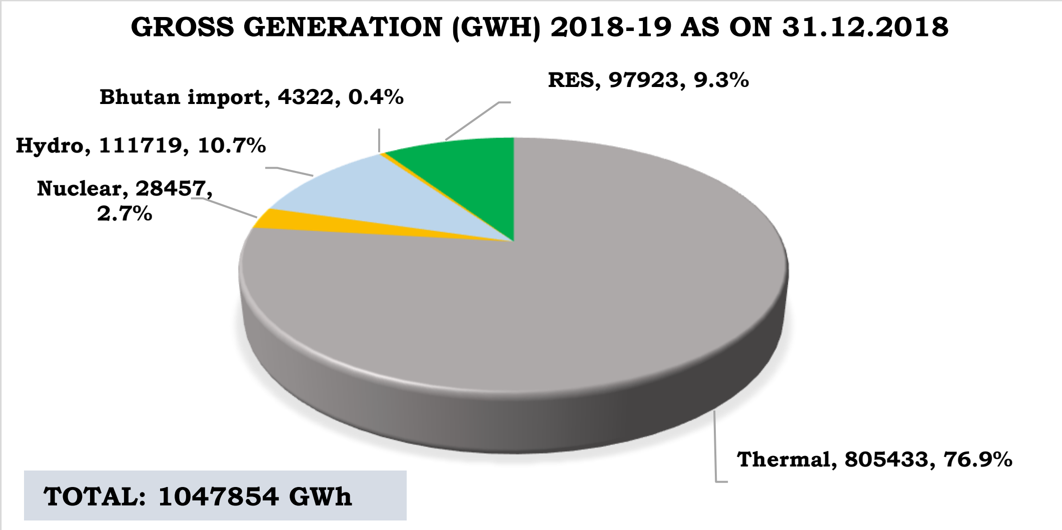
INSTALLED CAPACITY AS ON 31.01.2019

(FIGURES IN MW)

Sector	Hydro	Thermal					Nuclear	R.E.S (MNRE)	Total
		Coal	Lignite	Gas	Diesel	Total			
STATE	29878.8	63056.5	1290.0	7118.7	363.93	71829.13	0.00	1990.37	103698.30
PRIVATE	3394.0	74316.0	1830.0	10580.6	273.70	87000.30	0.00	70563.99	160958.29
CENTRAL	12126.4	53720.0	3240.0	7237.9	0.00	64197.91	6780.00	1527.30	84631.63
TOTAL	45399.2	191092.5	6360.0	24937.2	637.63	223027.34	6780.00	74081.66	349288.22
%	13.0	54.7	1.8	7.1	0.18	63.85	1.94	21.21	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



It can be observed from the above figures that although the installed capacity of thermal sources is about 64 % of the total installed capacity, the generation from these sources is around 77% of the total generation. Also, the share of RES in the total installed capacity is about 21 % but it's share in total generation mix is only 9 %.

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 10^{th} plan period (i.e. 2006-07) has come down to about 13% with bigger sizes of coal based units, transition to super critical coal based technology etc. The probable reason of higher percentage of coal based capacity in the generation capacity mix has been the abundant availability of 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 and a significant capacity is presently stranded due to lack of domestic gas and high cost of imported LNG. The country's installed capacity mix also has seen growth in nuclear based capacity from 4th five-year plan onwards and has grown up to 2% of the installed capacity by 2018 and further has plans to increase this share.

India being richly endowed with renewable energy sources has made significant capacity addition in the renewable energy sector in the recent times. With environmental concerns about climate change 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 renewables 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

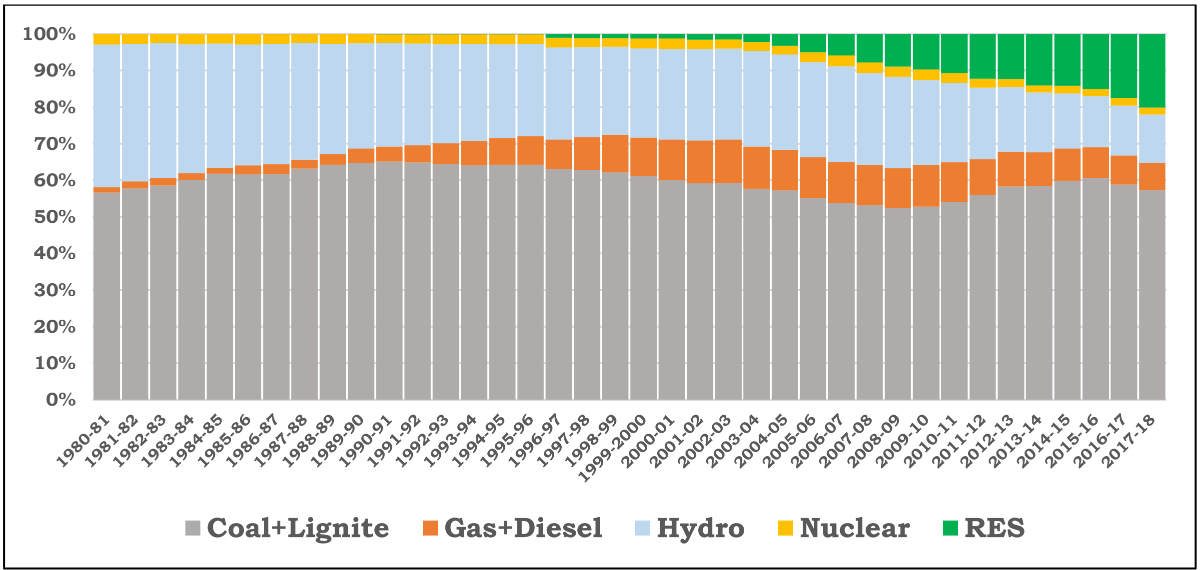
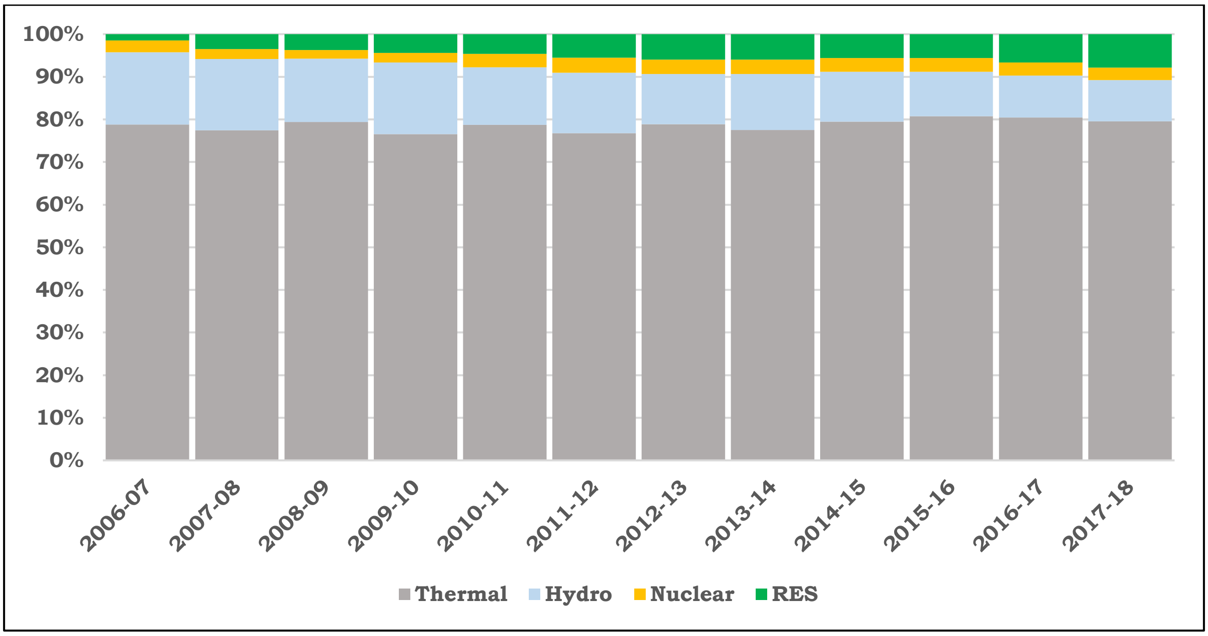


Exhibit 4

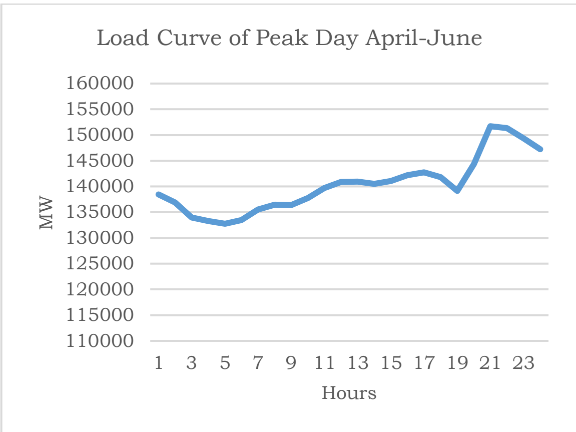
Generation mix of the country since the year 2006

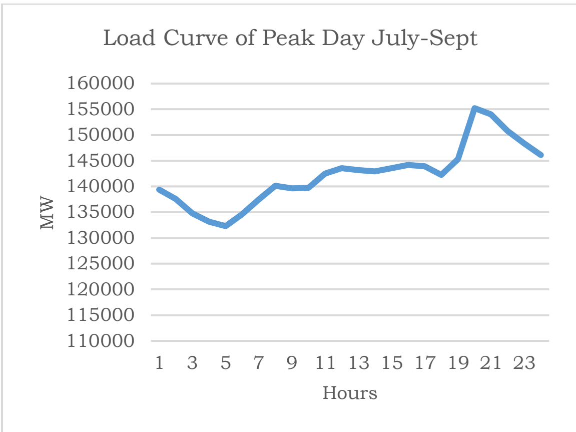


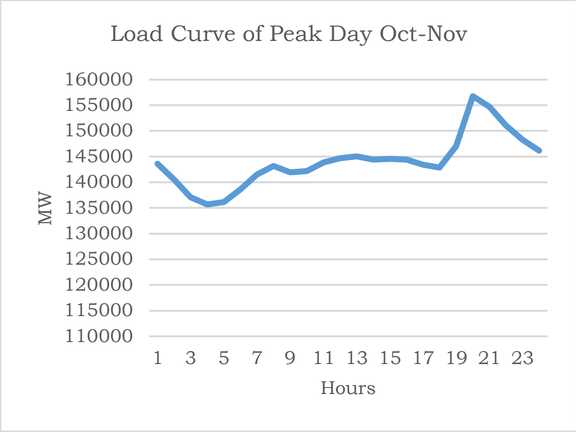
7. Present Load Profile of the country

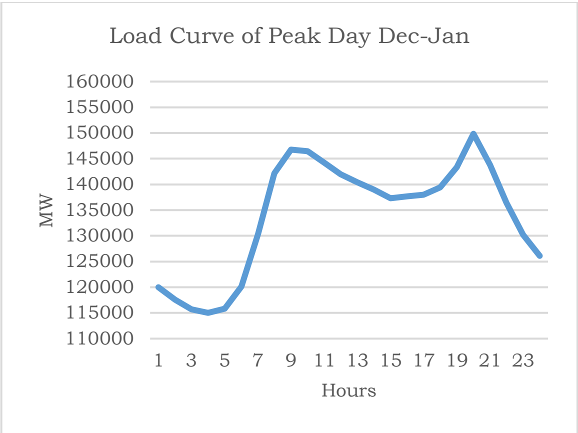
The country's load profile indicates that peak load is generally observed during morning hours and evening hours. However, the evening peaks are higher than the morning peaks. The All India peak load is observed generally in the month of October. The load curve of the country varies significantly during different seasons and the same is shown in **Exhibit 5**.

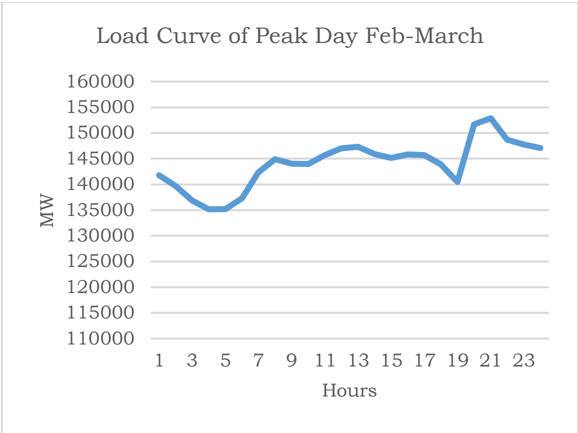
Exhibit 5











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

8.1. Inputs for the Study

i. Studies have been carried out to find out the optimal generation 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 constraints. The generation capacity mix for the year 2021-22 as projected in National Electricity Plan (NEP) Vol I (Generation) has been considered as the base capacity for the study. The base year of the study has thus been taken as 2021-22. Therefore, the study period from 2022-23 to 2029-30 has been considered to arrive at the optimal generation capacity mix for the year 2029-30.

ii. The projected installed capacity of the power plants of the country by the end of 2021-22 as per NEP is 4,79,419 MW comprising of 51,301 MW Hydro; 2,17,302 MW Coal; 25,736 MW Gas; 10,080 MW Nuclear, 175,000 MW RE has been considered as the base capacity.

iii. The 19th Electric Power Survey (EPS) 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 2031-32 with 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.

iv. The estimated peak electricity demand (MW) and electrical energy requirement (BU) in the years 2021-22, 2026-27 and 2029-30 are given in **Table 2**.

Table 2

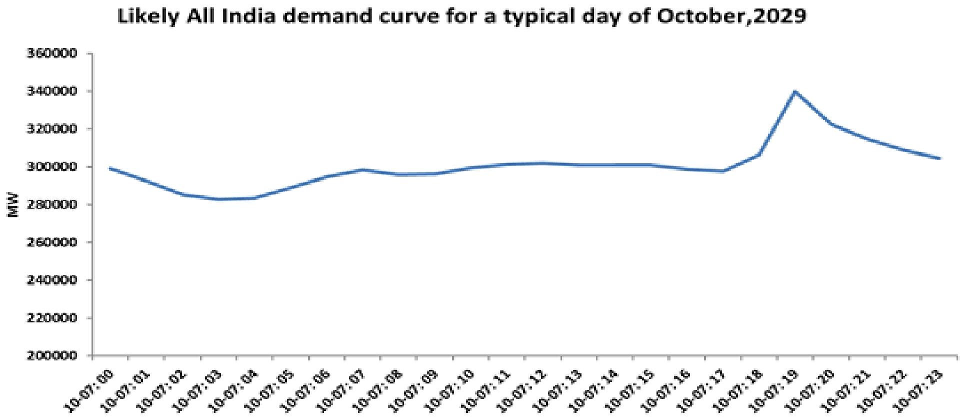
Projected Electricity Demand (As per 19th EPS)

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

v. The 19th EPS demand estimates the total demand on the electricity grid and has considered the energy contribution from the solar roof-top as negative demand. However, 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. 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**. However, the peak load during 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).

vi. 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



vii. Additional under construction and planned capacity addition of 13,762 MW of hydro, 6,800 MW of nuclear and retirement of coal based units of 25,572 MW has been considered from 2022-23 onwards.

viii. Studies have been carried out considering the following technologies as shown in **Table 3**.

Table 3

Technologies considered for the study

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

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

ix. 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, emission factors etc. in respect of all the existing, under construction, planned and candidate plants.

x. The reducing trend of the capital cost of RE technologies as well of battery energy storage technology has been considered in the study.

xi. Only 660 MW and 800 MW coal based supercritical units have been considered as candidate plants.

xii. It has been observed that there is deterioration in operational efficiency with part loading of units of coal based plants. In view of flexible operation required for coal based units due to RE penetration in the system, there would be loss in efficiency of coal based units. This characteristic has also been incorporated in the model for coal, gas and biomass based plants.

xiii. No additional gas-based capacity has been considered apart from existing capacity of about 25,000 MW.

xiv. Due to the unavailability of natural gas and high price of imported RLNG, fuel restriction for gas based plants has been considered and has been limited to present supply of the domestic natural gas.

xv. Nuclear capacity which has got in principle approval has been considered as candidate plants for the studies.

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

xvii. The total hydro capacity (Existing + Under construction + Planned) being considered is 64,089 MW which consists of 22.9 % storage type, 43 % run off the river with small pondage type, 6.6 % of run off the river,18.6 % multipurpose projects and 9% pumped storage type. Apart from this, small hydro projects (less than 25 MW) totaling to 5000 MW have also been considered as run off river type projects.

xviii. Hydro imports of the order of 4,356 MW from neighboring countries have also been considered.

xix. The actual 8760 hourly generation profile of solar and wind has been gathered from various states having RE generation. The annual CUF of solar power plants is estimated to be 22 % and that of wind power plants as 25.21 %.

xx. 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

xxi. 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 draught or excess rainfall in any particular year. For future hydro power plants, the design energy/flows in the respective river basin has been considered. 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.

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

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

8.2. Battery Energy Storage Systems

The cost of Battery Energy Storage system has been estimated in study 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 above inputs/assumptions using computer model ORDENA to find out the least cost option for system expansion for the study period beginning from 2022-23 to 2029-30.

The model determines the least cost optimal expansion path to arrive at the optimal generation capacity mix for all the years till 2029-30, taking into account all the technical/financial parameters for the study period.

The results of the generation capacity mix and likely generation dispatch based on the long term generation planning studies for the study period (2022-30) is shown in **Exhibit 7** and **Exhibit 8**. The actual generation dispatch however may vary based on actual day to day operations.

Exhibit 7

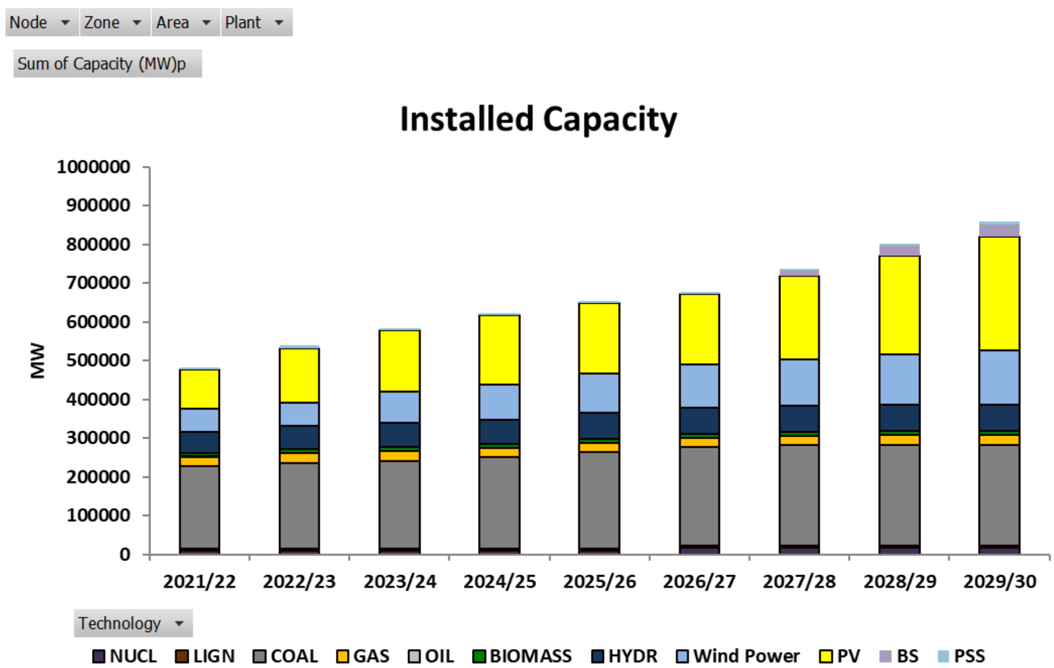
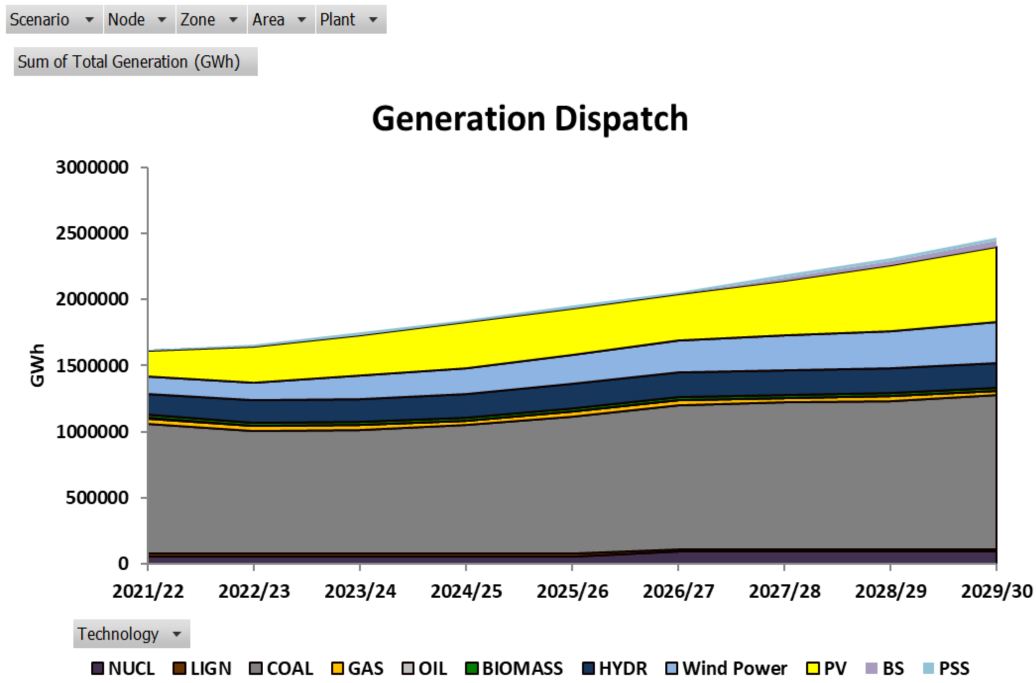


Exhibit 8



From the results, it is observed that the capacity expansion for coal based plants is not significant as compared to the solar and wind capacity addition. The model selects battery energy storage system from the year 2026-27 onwards, due to the reduction in cost of solar, and battery energy storage system. Model has not selected any new hydro and nuclear power plants apart from already planned projects. It is seen that renewable energy sources (solar + wind) installed capacity will become 440 GW by the end of year 2029-30 which is more than 50% of total installed capacity of 831 GW.

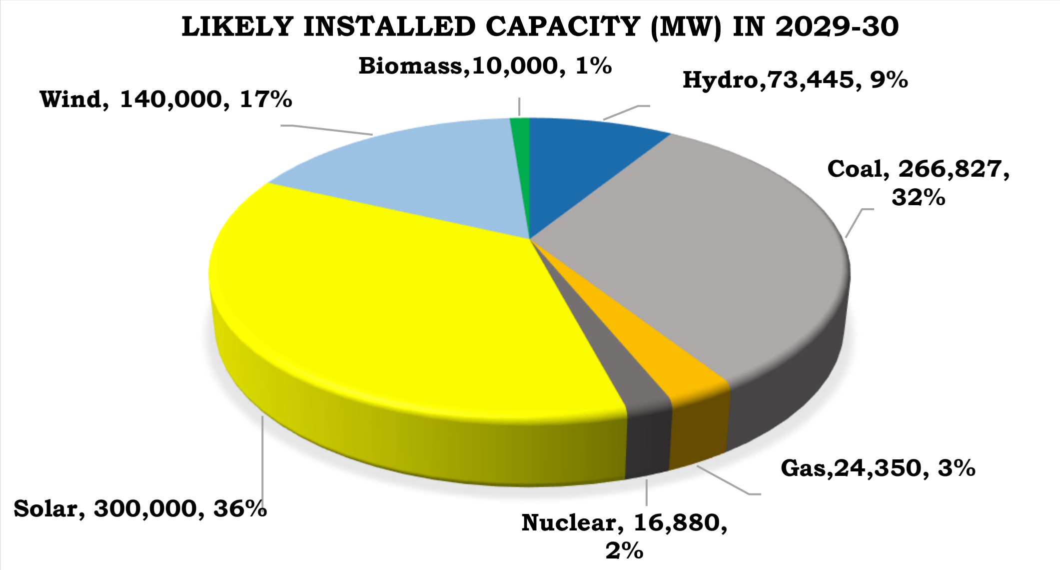
The likely installed capacity by the end of the year 2029-30 is given in **Table 4** and **Exhibit 9**.

Table 4
Likely Installed capacity by the end of 2029-30

Fuel Type	Capacity (MW) in 2029-30	Percentage Mix (%)
Hydro *	73,445	8.8
Coal + Lignite	2,66,827	32.1
Gas	24,350	2.9
Nuclear	16,880	2.0
Solar	3,00,000	36.1
Wind	1,40,000	16.8
Biomass	10,000	1.2
Total	8,31,502	
Battery Energy Storage	34,000MW/136,000MWh	

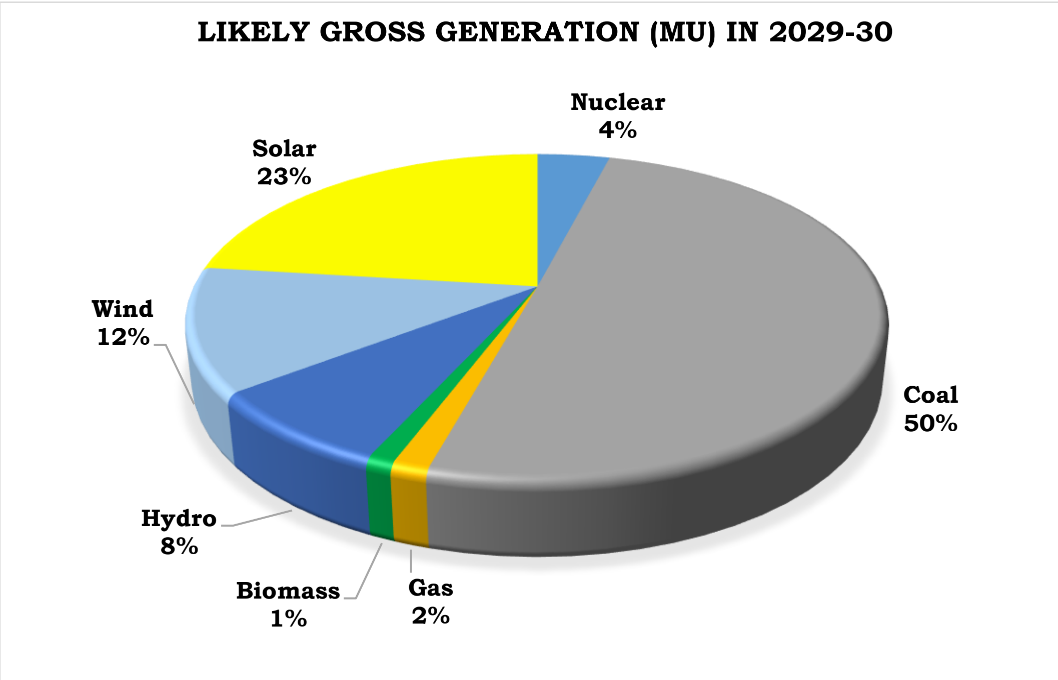
* including small hydro of 5000 MW and hydro imports of 4356 MW

Exhibit 9



The projected gross electricity generation (BU) during the year 2029-30 is likely to be 2,508 BU comprising of 1,297 BU from Thermal (Coal, Gas and Lignite), 887 BU from Variable RES, 197 BU from Hydro, 101 BU from Nuclear and 26 BU from Biomass as shown in **Exhibit 10**.

Exhibit 10



It can be seen from the above results in the year 2029-30 that non-fossil fuel (solar, wind, biomass, hydro & nuclear) based installed capacity is likely to be about 65% of the total installed capacity and non-fossil fuels contribute around 48% of the gross electricity generation in the year 2029-30.

8.3.2. Short Term studies - (Hourly Generation dispatch)

While the long term studies for the year 2029-30 are used 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 been carried out to assess the adequacy of various capacities to meet the demand at every instant of time at the lowest possible cost. Although, the system is to be designed for meeting the peak electricity demand and electrical energy requirement on a daily basis for the complete year of 2029-30, short term studies have been carried out on hourly basis for one week involving the critical days for verifying the adequacy of capacity worked out in long term planning studies. All the operational/financial parameters and technical characteristics of the power plant have been considered for the short term studies also to arrive at the least cost optimum generation dispatch from the available capacity on all the critical days.

The critical days are identified by analyzing the likely demand pattern and likely variable RE (Wind & Solar) generation during the year 2029-30. The critical days identified are maximum peak demand day, maximum energy demand day, maximum/minimum RE generation day, maximum/minimum solar generation day, minimum energy demand day, day with maximum variation in demand/net demand. The details of typical days identified for the short term studies are given in **Table 5**.

Table 5

Short Term scenarios considered (Critical Days)

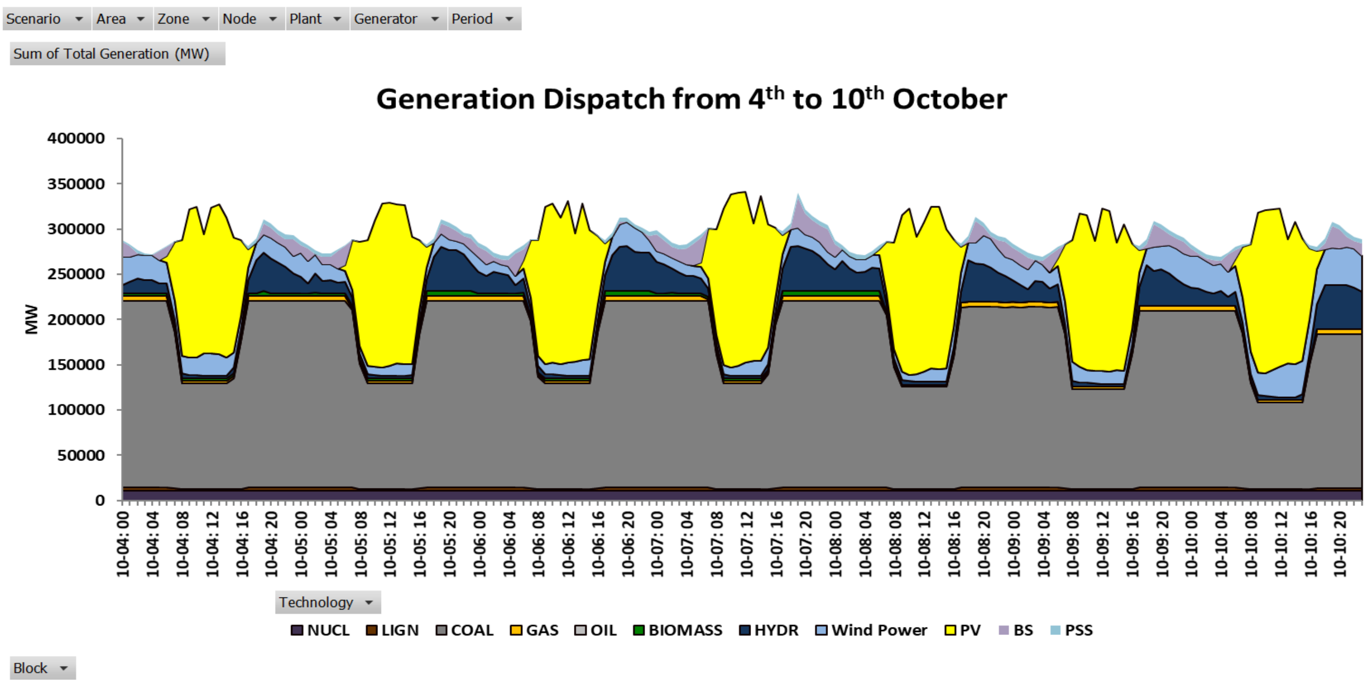
Sl. No.	Scenario	Day
1	Peak Day / Max Energy demand day	7th October, 2029
2	Maximum RE (Wind+Solar) generation day	3rd July, 2029
3	Maximum Solar generation day	25th March, 2030
4	Minimum Solar generation day	8th August, 2029
5	Minimum Energy demand day	14th December, 2029
6	Minimum RE (Wind+Solar) generation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

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 occurs in the month of October and is likely to be on 7th of October 2029. Also, it happens to be the maximum energy requirement day (7.21 BU). Therefore, the week containing 7th October (three days before and 3 days after 7th Oct) has been studied in detail.

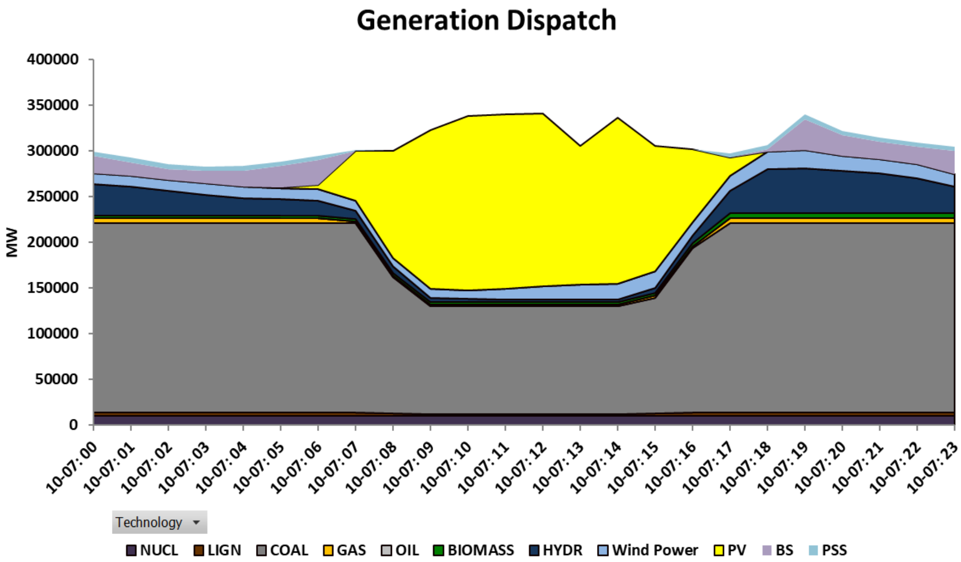
Typical generation dispatch for the week in which peak demand occurs is shown in the **Exhibit 11**.

Exhibit 11



Hourly generation dispatch for the peak day is shown in the **Exhibit 12**.

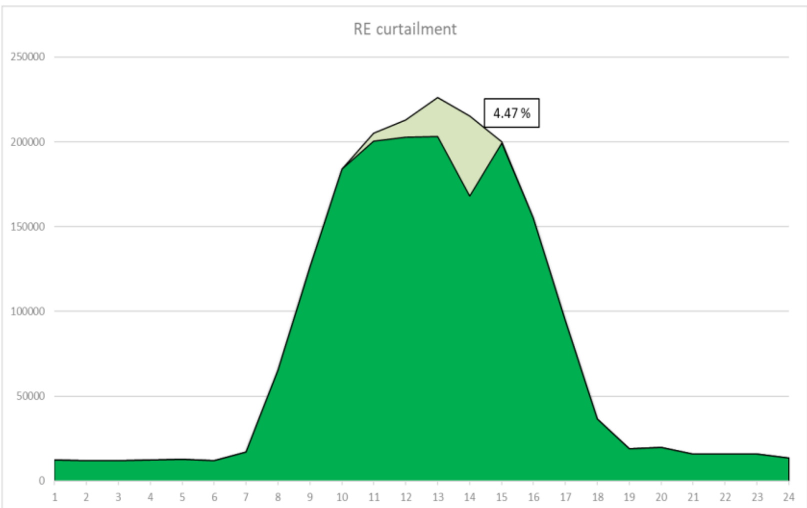
Exhibit 12



It has been observed that on this critical day when the peak demand occurs, the demand will be fully met with the generation capacity mix obtained from the long term studies. Further, it is seen that the coal capacity is running at 55% technical minimum load 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 20.72%. The Gross PLF of the coal based capacity is likely to be 72.72% on the day.

RE generation dispatch and curtailment is shown in the **Exhibit 13**. The curtailment on the peak day is likely to be around 4.47%.

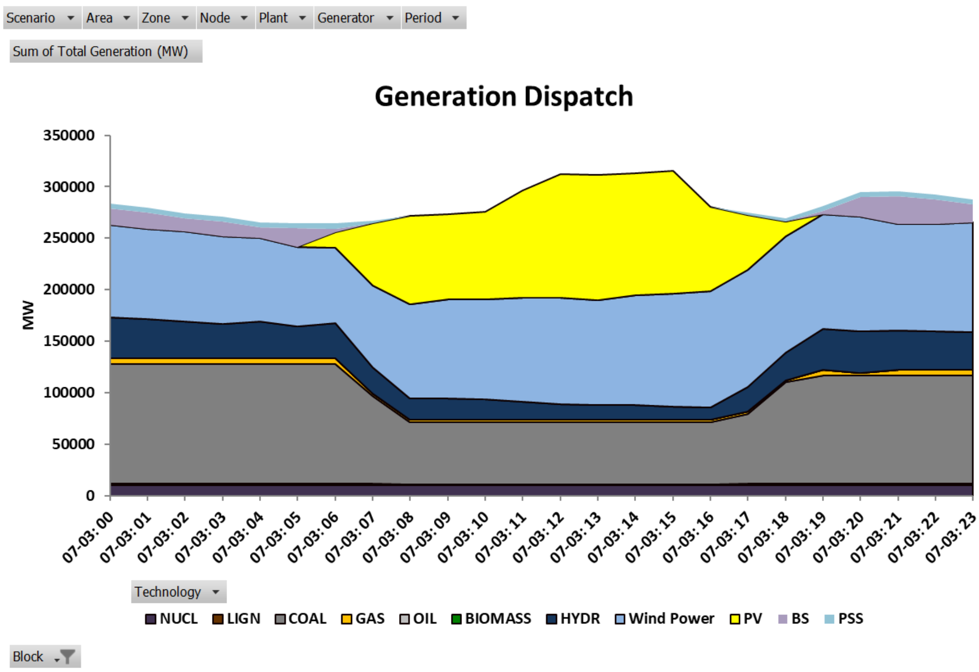
Exhibit 13



8.3.2.2. Maximum RE (Wind + Solar) Generation day – 3rd July, 2029

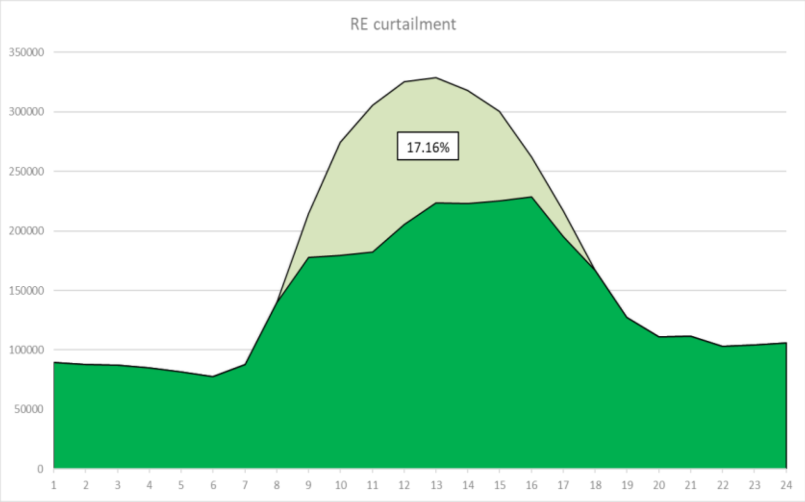
The system has to be resilient on the day when the maximum generation from RE (wind + solar) is available. The maximum generation from RE is likely to occur in the month of July, typically 3rd of July. The CUF of the wind capacity is likely to be maximum (69.79%). The hydro generation is also maximum during the month of July. Hourly generation dispatch for the maximum RE generation day is shown in the **Exhibit 14**.

Exhibit 14



It has been observed that on this critical day during which RE generation is maximum, the demand will be fully met with the generation capacity mix obtained from the long term studies. Due to higher availability of hydro and wind generation, the annual maintenance of the coal plants may be taken up during this period. It has been observed that RE generation could not be fully absorbed. The curtailment on this day is likely to be around 17.16%. RE generation dispatch and curtailment is shown in the **Exhibit 15**.

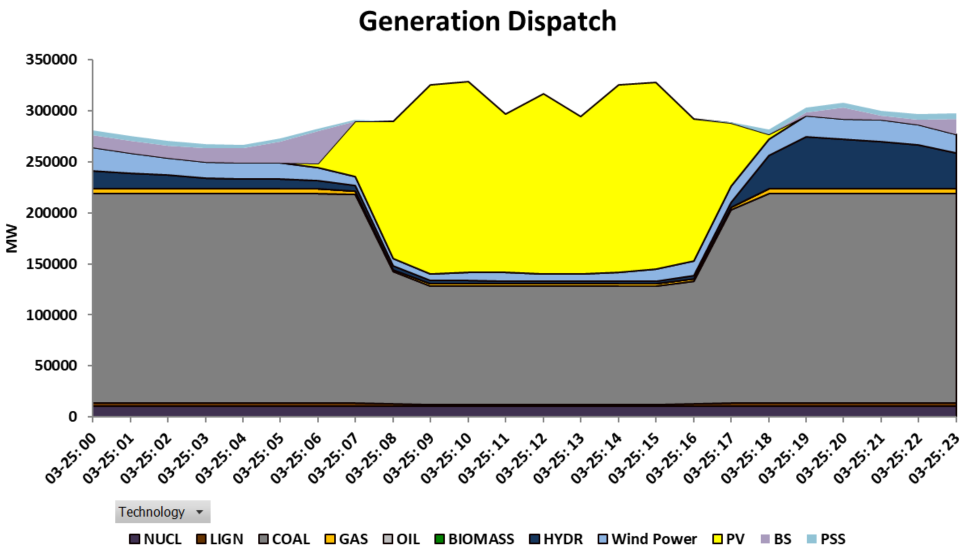
Exhibit 15



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

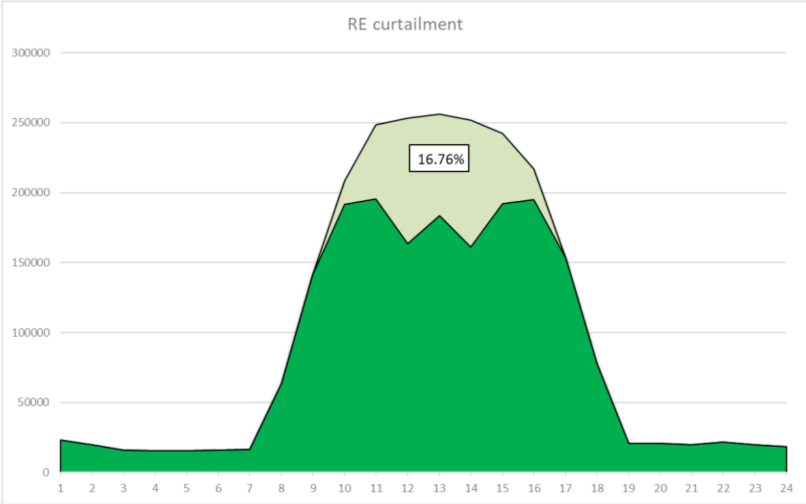
Studies have also been carried out on the week containing maximum solar generation day i.e. 25th March, 2030 to assess the adequacy of supply and RE curtailment. The CUF of solar capacity is around 28.00 % on this day. Hourly generation dispatch is shown in **Exhibit 16**.

Exhibit 16



It has been observed that on this critical day when solar generation is maximum, the demand will 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 curtailment on this day is likely to be around 16.76%. RE generation dispatch and curtailment on this day is shown in the **Exhibit 17**.

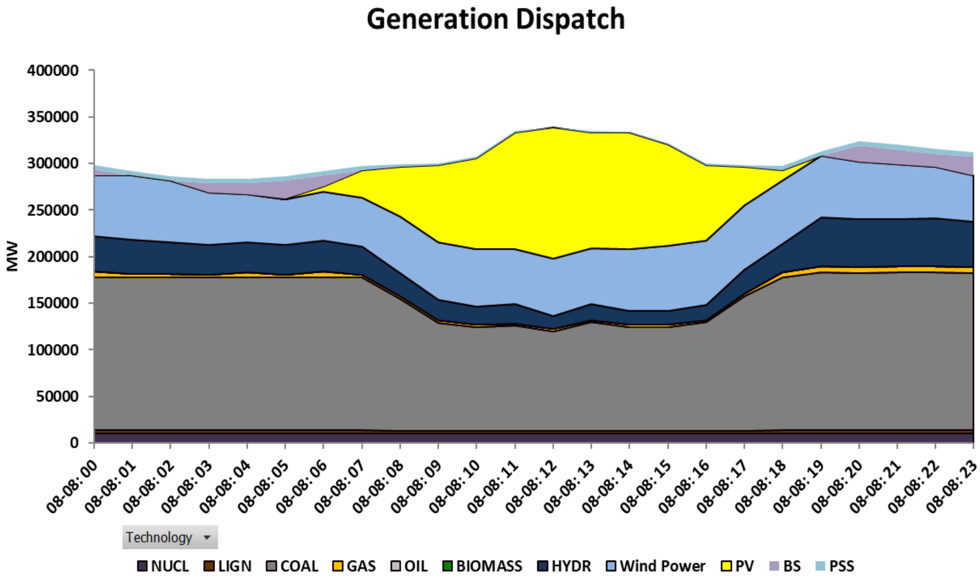
Exhibit 17



8.3.2.4. Minimum Solar Generation day – 8th August, 2029

Studies have also been carried out on the week containing minimum solar generation day i.e. 8th August, 2029 to assess the adequacy of supply and RE curtailment. The CUF of solar capacity is only 14.25%. Hourly generation dispatch on this day is shown in **Exhibit 18**.

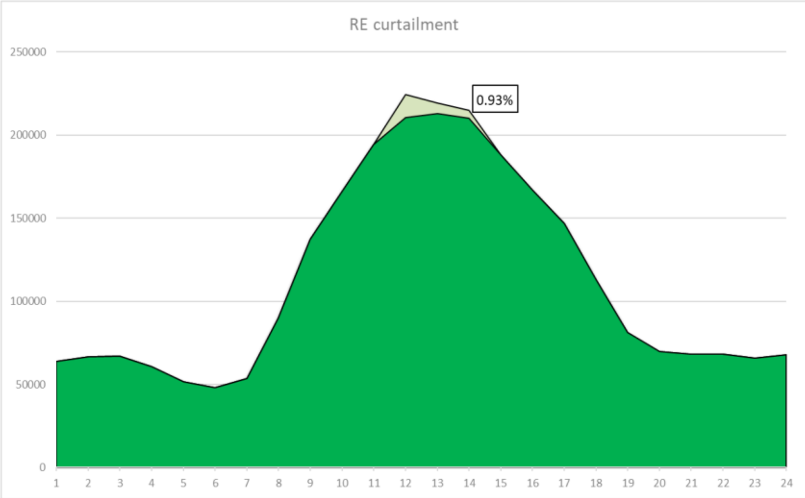
Exhibit 18



It has been observed that even on this critical day when solar generation is minimum, the demand will 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. The curtailment on this day will be minimal and is likely to be only

0.93%. RE generation dispatch and curtailment on this day is shown in the **Exhibit 19**.

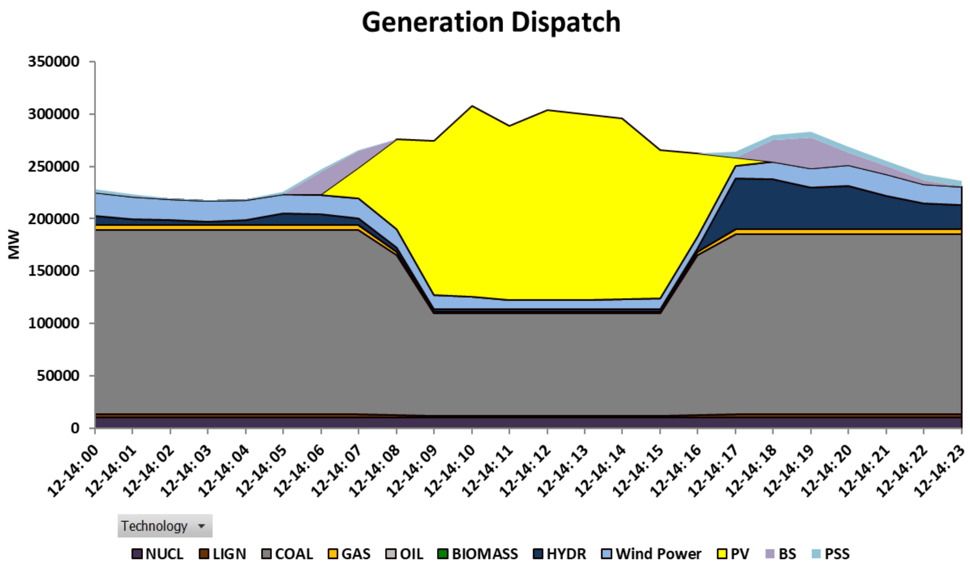
Exhibit 19



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

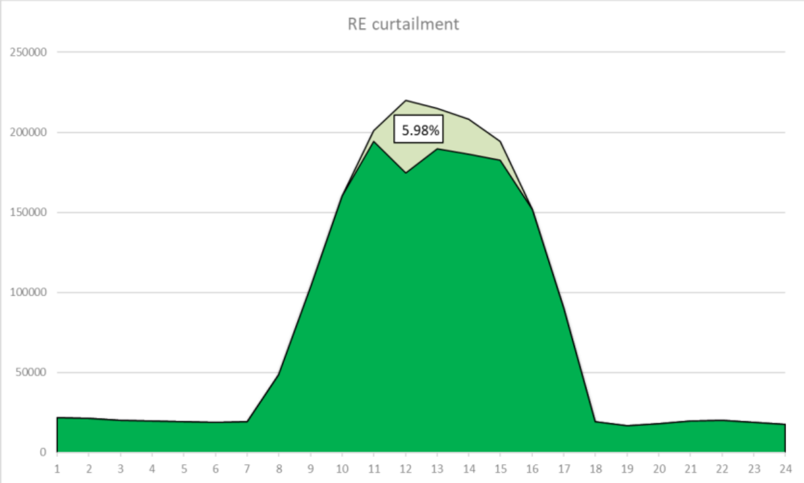
Studies have been carried out on the week containing minimum energy demand day i.e. 14th December, 2029 to assess the adequacy of supply and RE curtailment. The energy requirement is only 6 BU on this day. Hourly generation dispatch is shown in **Exhibit 20**.

Exhibit 20



It has been observed that during this critical day when energy demand of the system is minimum, the demand will be fully met with the supply side options as per the long term studies. It is observed that despite hydro and wind generation being less, RE curtailment on this day is likely to be around 5.98%. RE generation dispatch and curtailment on this day is shown in the **Exhibit 21**.

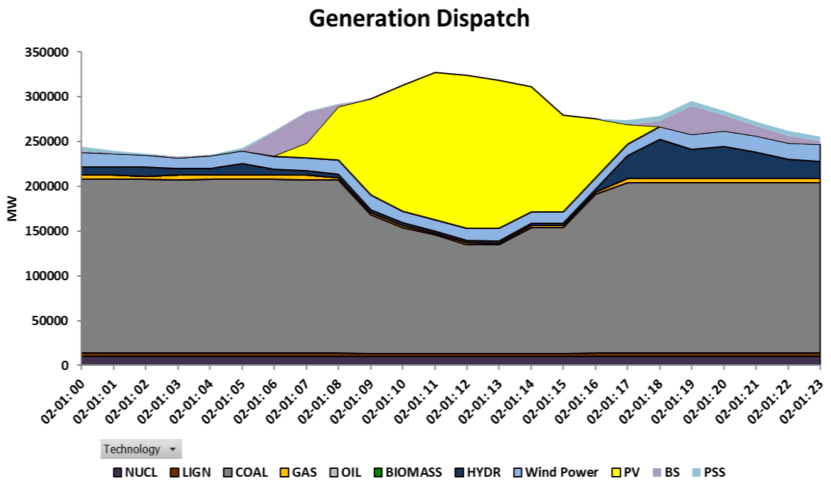
Exhibit 21



8.3.2.6. Minimum RE Generation Day – 1st February, 2030

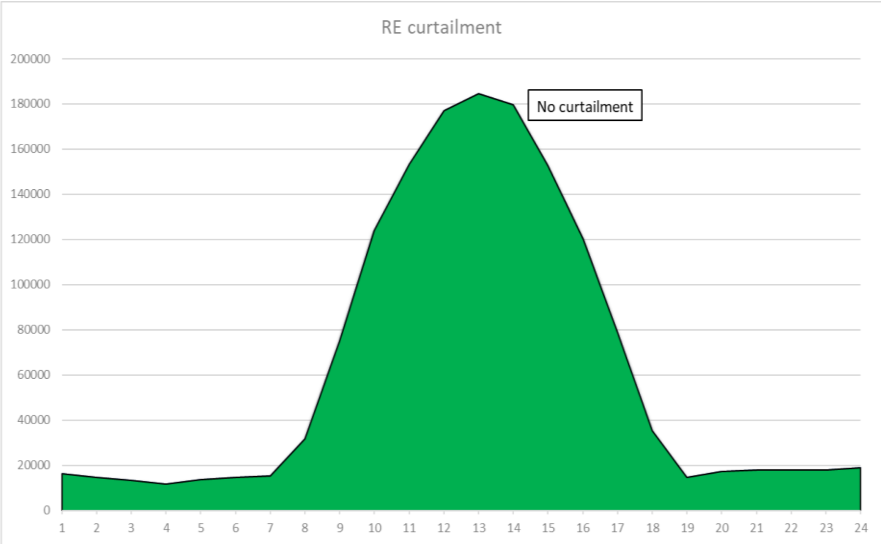
Studies have been carried out on the week containing minimum RE (solar + wind) generation day i.e. 1st February, 2030 to assess the adequacy of supply and RE curtailment. The CUF of solar and wind power plants is likely to be only 16.13% and 10.54% respectively on this day. It is also observed that likely hydro generation is also low on this day. Hourly generation dispatch is shown in **Exhibit 22**.

Exhibit 22



It has been observed that on this critical day when the generation from RE is minimum, the demand will be fully met with the supply side options as per the long term studies. It can also 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 71.77 %. It has been observed that RE generation is fully absorbed on this day as shown in **Exhibit 23.**

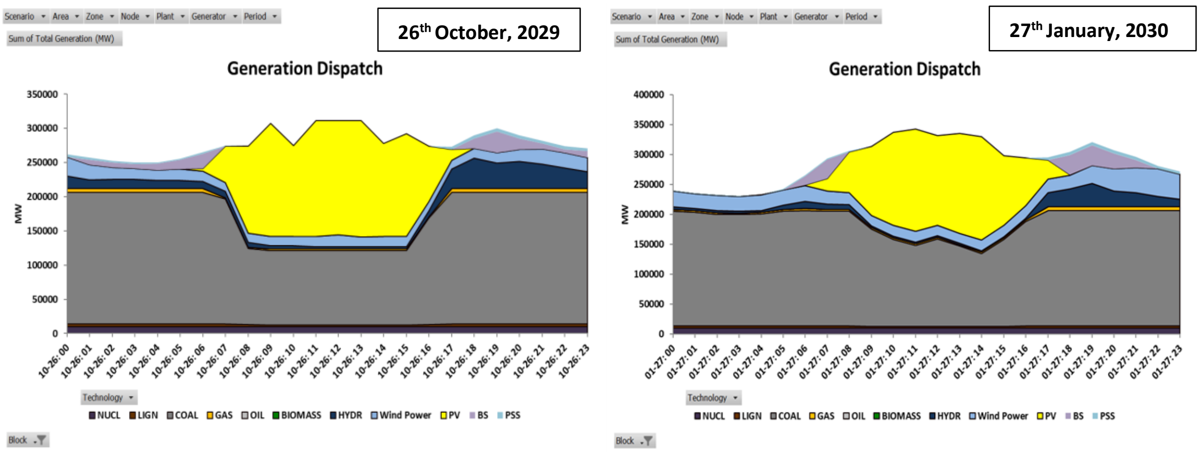
Exhibit 23



8.3.2.7. Maximum variation in net demand/demand days

Studies have been carried out for the likely days when the variation 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 284 GW and minimum hourly net demand is 124 GW. The maximum variation in the total demand is likely to occur on 27th January, 2030 during which the maximum hourly total demand is 320 GW and minimum hourly total demand is 231 GW. Hourly generation dispatch is shown in **Exhibit 24.**

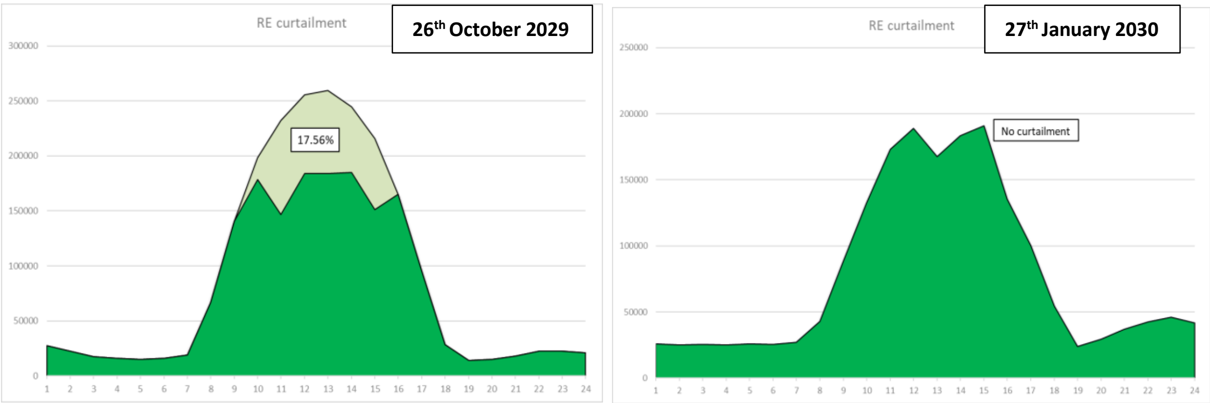
Exhibit 24



It has been observed that on this day (26th October) the peak demand is on the higher side and thus the coal-based capacity on bar 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 curtailment on this day is about 17.56%.

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 and there is no curtailment. The RE curtailment is shown in the **Exhibit 25**.

Exhibit 25



8.3.3. Study on impact of reducing minimum technical load of coal plants on RE curtailment

The curtailment of RE generation observed in the short term studies can be reduced by reducing the technical minimum load of coal based plants or by increasing the battery energy storage system size. The curtailment of RE can also be reduced if the nuclear power plants participate in the flexible operation.

The minimum technical load of coal based power plants has been considered as 55% (as notified by CERC) in the studies. From the short term studies carried out for critical days mentioned above, it has been observed that RE curtailment varies between 0 - 17% as shown in the **Table 6**.

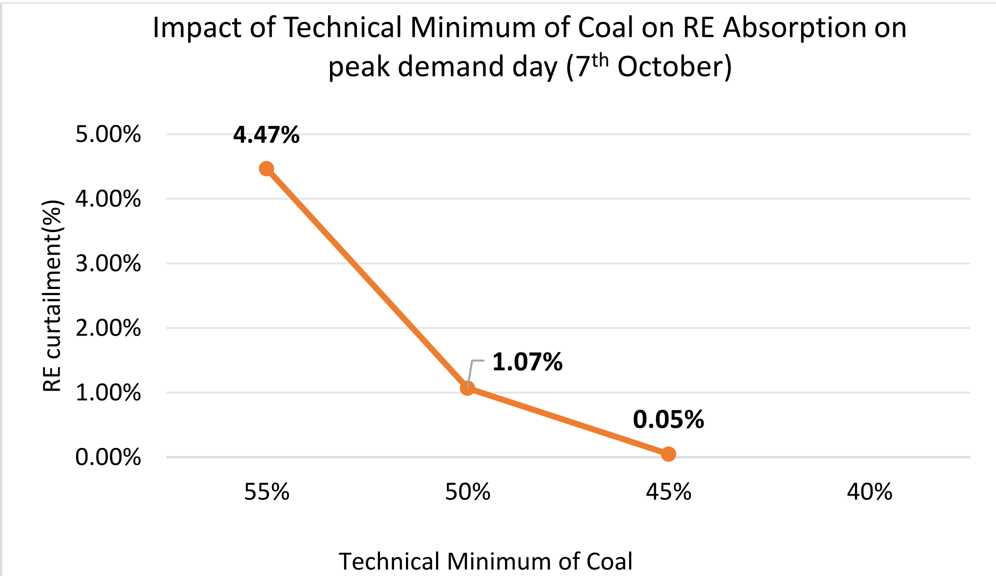
Table 6

RE curtailment on critical days

Sl. No.	Scenario	Day	RE Curtailment
1	Peak Day / Max Energy demand day	7th October, 2029	4.47 %
2	Maximum RE (Wind+Solar) generation day	3rd July, 2029	17.16 %
3	Maximum Solar generation day	25th March, 2030	16.76 %
4	Minimum Solar generation day	8th August, 2029	0.93 %
5	Minimum Energy demand day	14th December, 2029	5.98 %
6	Minimum RE (Wind+Solar) generation day	1st February, 2030	No curtailment
7	Maximum Variation in demand day	27th January, 2030	No curtailment
8	Maximum Variation in Net demand day	26th October, 2029	17.56 %

The RE curtailment is around 4.47% on 7th October 2029 (i.e. the peak demand day). In order to study the impact on reduction on RE curtailment by lowering the minimum technical load of coal based plants, a study has been carried out by reducing the minimum technical load from 55% to 50% and 45% on this day. The impact of reducing minimum technical load on curtailment of RE generation on peak demand day is shown in the **Exhibit 26**.

Exhibit 26



During the course of above analysis, it was observed that curtailment can be reduced 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. A reduction of approximately 3 % in the RE curtailment 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.

8.3.4. 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. 7th October (peak demand day) and 3rd July (maximum RE 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% due to efficiency drop on part load operation of coal based power plant on 7th October and 1.2% on 3rd July.

8.3.5. 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 also been carried out apart from the studies for critical days as the share of renewables (wind and solar) increases in the system. 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 also come down due to draught 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 2029) having minimum solar and wind generation day i.e. 3rd 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% hydro generation combined together during the week (4th Oct to 10th Oct 2029) having All-India peak demand day i.e. 7th Oct.

8.3.5.1. 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, if the variable RE (wind & solar) generation is reduced by 10% during the week, the demand will not be fully met with the generation capacity mix as per the long term studies. However, it has been observed that if the availability of coal based power plants is increased by only 1%, the demand will be fully met and RE generation may be fully absorbed.

Generation dispatch on the day is shown in the **Exhibit 27**. RE generation dispatch and curtailment is shown in **Exhibit 28**.

Exhibit 27

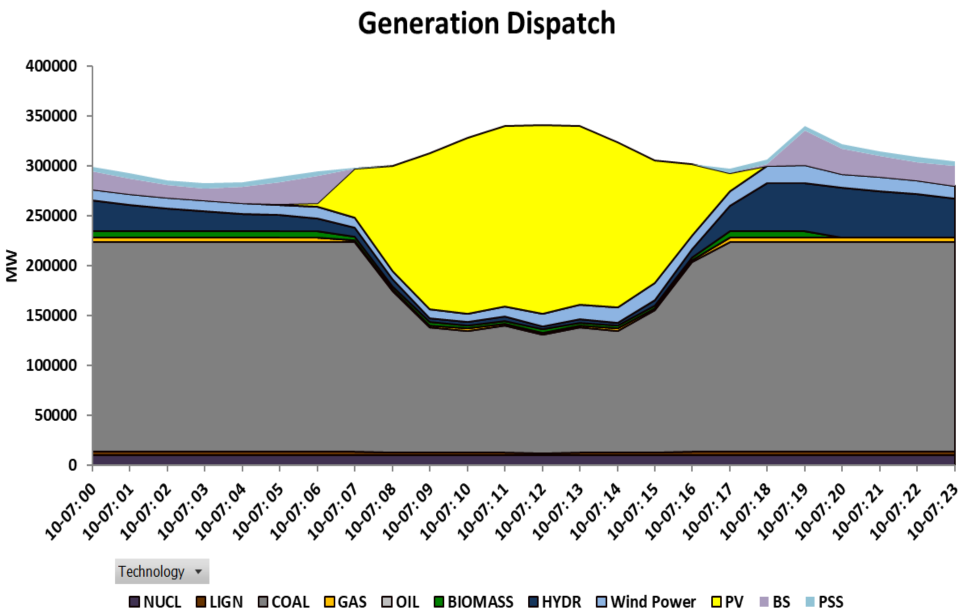
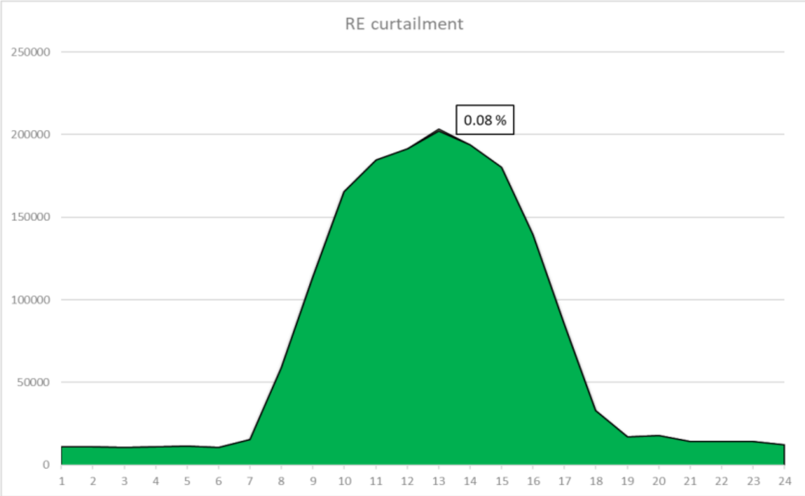


Exhibit 28



8.3.5.2. 10% reduction in Solar and Wind generation during the week having minimum solar and wind generation day i.e. 3rd Feb

The week containing the day on which the minimum RE generation is observed i.e. 1st February has also 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 will be fully met with the supply side options 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 29**. RE generation dispatch and curtailment is shown in **Exhibit 30**.

Exhibit 29

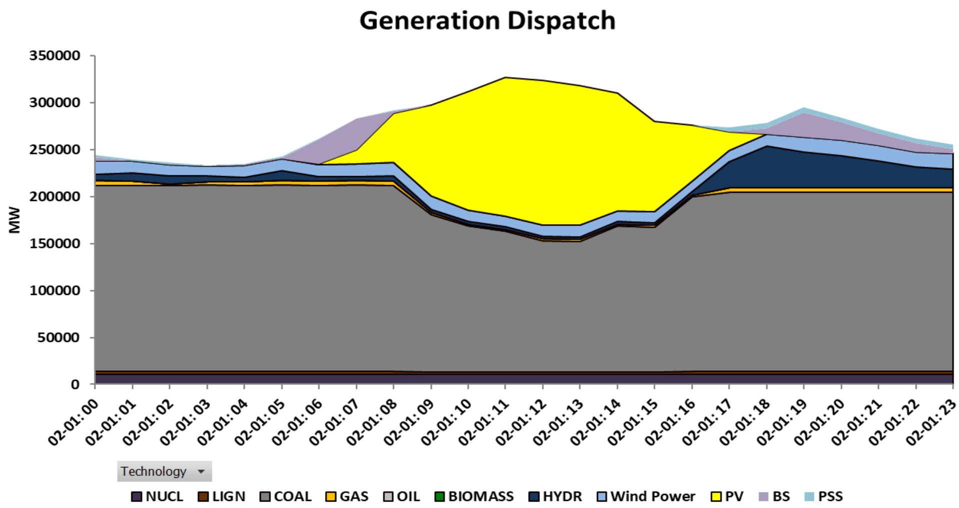
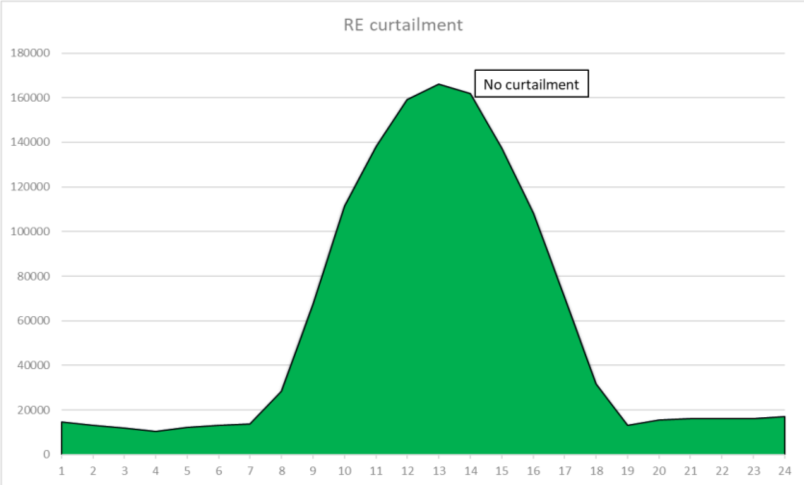


Exhibit 30



8.3.5.3. 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 draught 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 (draught in year 2029-30). Generation dispatch on the day is shown in the **Exhibit 31**.

It has been observed that on the day when the peak electricity demand is maximum, if the hydro generation is reduced by 6%, unserved energy may be observed during few hours of the day. However, studies show that with 1 % increase in the availability of the coal based capacity, the demand is fully met during the day. It is also observed that the generation from RE sources may not be fully absorbed due to various technical constraints. The curtailment on this day is likely to be around 4.77%. RE generation dispatch after increasing the coal capacity availability and resulting curtailment is shown in the **Exhibit 32**.

Exhibit 31

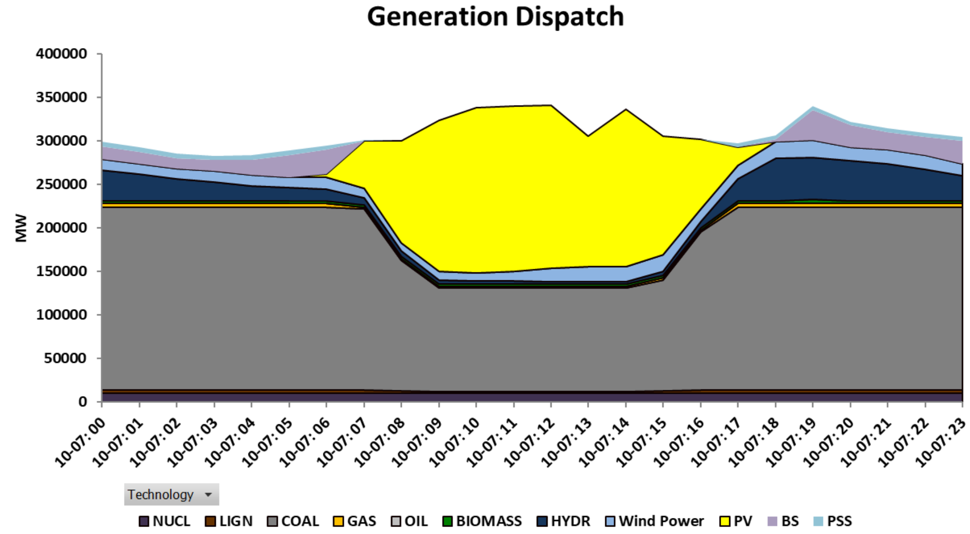
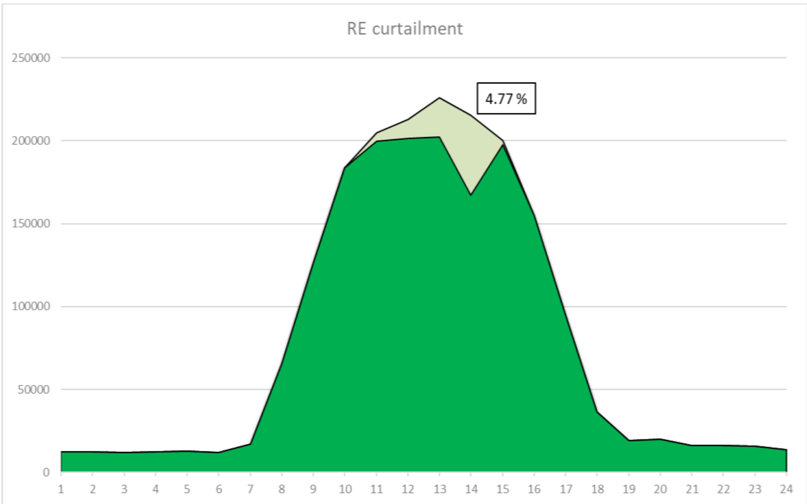


Exhibit 32



8.3.5.4. 10% reduction in RE generation and 6% hydro generation combined together during the week having All-India peak demand day i.e. 7th Oct

The extreme eventuality of a draught year (6% less hydro generation) combined with reduced variable RE (solar and wind) generation (10% reduced RE generation) also 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 supply side options as per the long term studies. However, if the availability of the coal based capacity is increased by 1.5%, the demand can be fully met. Generation dispatch on the peak day with this sensitivity is shown in the **Exhibit 33**.

The generation from RE sources may not be fully absorbed due to technical constraints on this day. However, the RE curtailment on this day is likely to be only 0.1%. RE generation dispatch after increasing the coal capacity availability and resulting curtailment is shown in the **Exhibit 34**.

Exhibit 33

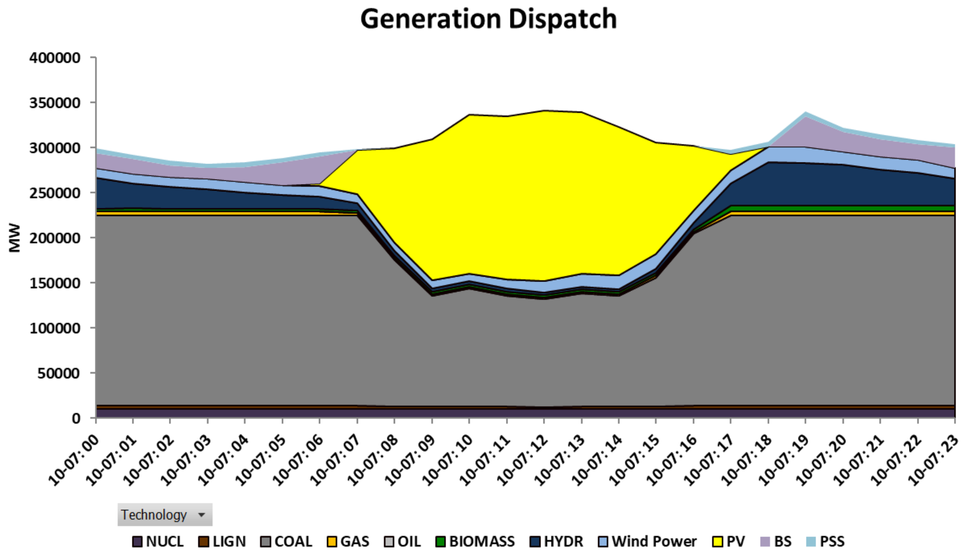
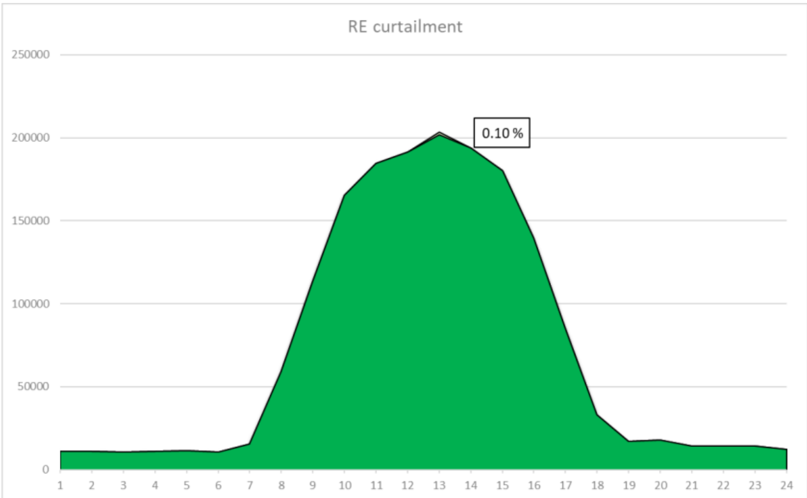


Exhibit 34



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 tonnes 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 December 2018, percentage of non- fossil fuel in installed capacity was 36.15 %. Studies for the year 2029-30 shows that it is likely to increase to 64.9% in March 2030. However, as per INDC target, the percentage of non- fossil fuel in installed capacity is to be 40% by 2030. **Table 7** give the percentage of non-fossil installed capacity by the end of 2029-30.

Table 7

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

(Figures in MW)

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	8,31,502	2,91,177	5,40,325	64.9%

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

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 1154 MT **(Table 8).**

Table 8

Likely annual CO_2 Emissions

	Year 2021-22 (as per NEP)	Year 2029-30
CO_2 Emissions Million Tonnes	1026	1154*

*Actual CO2 emissions may differ depending the RE generation, various technical constraints associated with coal plants.

11. Conclusions

The long term study results for the period 2022-23 to 2029-30 is the 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 also honours all the technical constraints associated with various technologies. Grid scale batteries energy storage technology has also been considered for finding out 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 results of the studies show that the installed capacity by the end of 2029-30 is 8,31,502 MW which includes Hydro 64,089 MW, Small Hydro 5000 MW, Hydro Imports 4,356 MW, Coal 2,66,827 MW, Gas 24,350 MW, Nuclear 16,880 MW, Solar 300,000MW, Wind 140,000 MW and Biomass 10,000 MW along with a Battery Energy Storage capacity of 34,000 MW/136,000 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 may be met.

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 was found that the energy requirement at every instance of time has been met with all the technical/operational constraints. It was also observed that the RE generation which could not be absorbed in the system is in the range of 0% (on minimum RE generation day) to 17% (on maximum RE generation day). The curtailment 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 from reservoir of hydro plants etc. In order to study the impact on reduction of RE curtailment 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 curtailment gradually reduces 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.

Sensitivity analysis for contingency scenarios have also been carried out during the week of 7th October, 2029 by considering 10% reduction in solar and wind generation during 4th - 10th Oct 2029, 10% reduction in solar and wind generation during 1st - 7th Feb 2029, 6% reduction in hydro generation during 4-10th Oct 2029, 10% reduction in RE generation and 6% hydro generation combined together during 4th -10th Oct 2029.

The results of the sensitivity studies show that with the base case installed capacity along with a battery energy storage capacity of 34,000 MW/136,000 MWh there may be unserved energy at few instances of time. However, it has been observed that if the availability of coal based power plants is increased by 1% to 1.5%, the demand is likely to be fully met.

Further, the impact on efficiency due to part load operation and CO_2 emissions from coal-based power plant has also been studied for the peak demand day i.e. 7th Oct, 2029 and maximum RE generation day i.e. 3rd July 2029. It is observed that CO_2 emissions may increase to the tune of 1% due to efficiency drop on account of part load operation of coal based power plant on 7th October and 1.2% on 3rd July 2029. The CO_2 emissions for the year 2029-30 has also been studied and the study results show that CO_2 emissions from the Power Sector is likely to be 1154 MT.

ANNEXURE

Annexure-I/1

ASSUMPTIONS

Likely installed capacity by 2021-22 as per NEP projections (Base Capacity considered):

Hydro	:	51,301 MW
Coal	:	2,17,302 MW
Gas	:	25,736 MW
Nuclear	:	10,080 MW
Solar	:	1,00,000 MW
Wind	:	60,000 MW
Biomass	:	10,000 MW
Small Hydro	:	5,000 MW
Total IC by 2021-22	:	4,79,419 MW

Hydro imports of 4356 MW

Under construction, Planned and Candidate plants considered for the period 2022-23 to 2029-30:

Technology	Additional Planned/Under construction capacity b/w 2022-23 & 2029-30 (MW)	Candidate (new plants) IC considered (MW) from 2022-2030	Unit size (MW)
Hydro	13,762	75,000	500
Coal (Pithead)	-25,572	105,380	660 & 800
Coal (Load-centered)		44,780	660 & 800
Gas	-430	0	0
Nuclear -LWR	6,800	7,000	1,000
Nuclear -PHWR		7,000	1,000
Solar	0	3,50,000	10,000
Wind	0	80,000	10,000
Biomass	0	10,000	1,000
Small Hydro	0	5,000	1,000
Pumped Storage	0	5,000	1,000
Battery Energy Storage	0	80 GW/320 GWh	1GW/4GWh

* Negative sign indicates retirement of units.

Annexure-I/2

COST PARAMETERS

Studies have been carried out considering the following cost parameters 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)#	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	11.70 Cr	2.5% of Capex	8	35
Small Hydro	7.60 Cr	2.5% of Capex	5	35
Solar	4.50 Cr	1.25% 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	12.87 Cr	2.5% of Capex	8	35
Battery Energy Storage	7 Cr	2% of Capex	0.5	10

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.

Other assumptions-

- All costs considered are with respect to the base year of the study i.e. 2021-22.
- Discount rate - 9%
- Capital costs of wind plants kept constant at ₹ 6 Cr from 2021-22 to 2029-30.
- Capital costs of solar plants uniformly reduced from ₹ 4.5 Cr in 2021-22 to ₹ 4.1 Cr during the year 2029-30.
- Cost of battery energy storage 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.
- No limitation on depth of discharge has been considered for the batteries in the studies.
- Cost of unserved energy – ₹ 20/kWh.
- No transmission constraints have been envisaged in the system.
- All candidate hydro plants and pumped storage plants have reservoir size of 3 hours (capable to give 3 hours of continuous generation at rated capacity).
- Fuel quota limitations on Gas (presently available to power sector from domestic sources).
- Nuclear to run at constant load with availability limited to 68%.

- Biomass is limited to annual PLF of 30% due to fuel constraints (seasonal fuel availability).

Annexure-I/3

TECHNICAL PARAMETERS

Technology	Type	Availability (%)	Ramping (%/min)	Min. Technical. (%)	Start -up time (hr)		
					Hot	Warm	Cold
Coal	Existing/Planned	86.92	2	55	2	5	10
	Candidate	88	2	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 (run off river)	Existing/Planned	As per profile	50	-	-	-	-
Hydro (reservoir)	Existing/Planned	As per profile	50	-	-	-	-
	Candidate	As per profile	-	-	-	-	-
Solar	Existing/Planned	As per profile	-	-	-	-	-
	Candidate	As per profile	-	-	-	-	-
Wind	Existing/Planned	As per profile	-	-	-	-	-
	Candidate	As per profile	-	-	-	-	-
Battery Energy Storage	Candidate	100	NA	-	-	-	-

Technology	Type	Heat Rate* (MCal/MWh)		Aux. Consum. (%)	Min. online time (hr)	Min. offline time (hr)	Start-up fuel consumption (MCal/MW)		
		At max loading	At min loading				Hot	Warm	Cold
Coal	Existing/ Planned	2300 to 2879	2438 to 3052	7.3	6	4	600	1000	1800
	Candidate	2175	2240	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	2571 to 2777	2571 to 2777	10	6	4	-	-	-
	Candidate	2777	2777	10	-	-	-	-	-
Biomass	Existing/ Planned	3000	3153	8	6	4	600	1000	1800
	Candidate	3000	3153	8	6	4	600	1000	1800
Hydro	Existing/ Planned	-	-	0.7	-	-	-	-	-
	Candidate	-	-	0.7	-	-	-	-	-
Battery Energy Storage	Candidate	-	-	12	-	-	-	-	-

* As per the curve of heat rate vs loading

Annexure-I/4

VARIABLE COSTS*

Technology	Existing (₹/kWh)	Candidate (₹/kWh)	Escalation per year (%)
Coal	1.2 to 3.98	1.33, 1.42 & 2.03 (Pithead) 3.13, 3.35 & 3.57 (load-centered)	2.5
Lignite	1.22 to 3.11	-	2.5
Gas	2.2 to 3.19	-	2
Nuclear	0.85	0.85	0
Biomass	7	7	2

*As in 2016/17