Estimating Energy Storage Requirements for Tamil Nadu Grid

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Abbreviations

BESS	Battery Energy Storage System
CEA	Central Electricity Authority
CAGR	Compounded Annual Growth Rate
CAPEX	Capital Expenditure
CGS	Central Generating Station
CUF	Capacity Utilization Factor
CoMETS	Competitive Market Evaluation Tools or Storage
DG	Diesel Generator
ESS	Energy Storage System
FGD	Fuel Gas Desulphurizer
FY	Financial Year
GW	Giga Watts
GOI	Government Of India
HRS	High Renewables Scenario
kW	kilo Watts
Li-Ion	Lithion Ion
LRS	Low Renewables Scenario
MNRE	Ministry of New and Renewable Energy
MoP	Ministry of Power
MRS	Minimum Renewables Scenario
MW	Mega Watts
MU	Million Units
NEP	National Electricity Plan
PLF	Plant Load Factor
PPA	Power Purchase Agreement
RE	Renewable Energy
RTC	Round The Clock
SLDC	State Load Dispatch Centre
SRLDC	Southern Regional Load Dispatch Centre
T&D	Transmission and Distribution
TANGEDCO	The Tamil Nadu Generation and Distribution Corporation
TEDA	Tamil Nadu Energy Development Agency

1. Executive Summary

Tamil Nadu is one of the leading states for renewable energy in India. The state has a total installed capacity of 28 GW (as on 31st March 2020) of which 47% (approximately 13 GW) came from renewables. To make a comparison with India as a whole, India's total installed renewable capacity as on March 31, 2020 was 88 GW, and Tamil Nadu constituted around 24% of the total installed capacity. In terms of generation, the state has progressed well over the last 5 years with more than 23% of generation coming from renewables, as on 31st March 2020 (MNRE, 2020).

The state enjoys a very high potential of wind (68.75 GW at 120 metres). It is endowed with four prominent passes having high wind potential, due to the tunnelling effect during South-West monsoon. Tamil Nadu also has a good potential of solar (17.67 GW) (MNRE, 2020). The last couple of years has seen an accelerated increase particularly in solar capacity addition with 2019-20 recording the highest YOY growth of 53%. The state has also set itself a target of 9 GW of solar capacity by 2023 as per the state's 2019 Solar Energy Policy (TN Solar Policy, 2019). High renewable penetration for Tamil Nadu is likely to bring its own challenges for the state grid operator and the state utility Tamil Nadu Generation and Distribution Corporation Limited (TANGEDCO). The state faced curtailment for wind power plants averaging around 30-35 percent of generation in the peak season during 2012-15; it averaged at 20-25% in FY2019-20 (Renewable Energy: Curtailment is a bane, 2020). Besides, there is a big question on capability of balancing the must-run RE plants with thermal power plant operations. Coal plant operators are faced with the challenge of using their asset as a flexible resource that can provide seasonal and daily ramps, due to possible technical and operational constraints.

Tamil Nadu is at a junction in its power generation capacity building stage where it is contemplating to review addition of over 14.6 GW (TN Policy Note, 2020) of coal plant assets in the next decade. Out of these 14.6 GW coal plants, 5.7 GW are already under construction or in the last stage of planning.

Hence, it is critical to examine how much RE can be added in this decade in Tamil Nadu and at what cost of flexibility in the grid. Can coal addition be minimized and can Tamil Nadu become a model state in India in the efforts to mitigate the impacts of climate change? In this context, the present study (jointly undertaken by WRI India and CES) evaluates the benefit of energy storage systems to seamlessly integrate RE onto the state's grid. Additionally, the study highlights how much energy storage should the state plan for under high RE, low RE and minimum RE scenarios. The study makes use of an optimization model, Python for Power System Analysis (PyPSA) for analyzing dispatch of resources and evaluating storage requirements. Further, the study also undertakes a techno-commercial project analysis through CoMETS platform to demonstrate costs and benefits of energy storage at the site level in Tamil Nadu.

The study considers two years, 2025 and 2030, to estimate battery energy storage needs for the following scenarios:

- **High Renewables Scenario (HRS)**: Assumes that the state will reach its targets wherever it is specified for the resource. In the absence of a state-specific target, it is assumed that the state will match the allocated state target based on the Central Government targets

Years	Wind Capacity (GW)	Solar Capacity (GW)	Peak Demand (GW)	Annual power demand (MU)	% Annual Demand met by RE
2020 (base line)	9.3	3.9	17.3	110,815	23%
2025	14.9	8.8	20.9	129,976	33%
2030	28.5	18.9	26.4	171,149	42%

Table 1: High RE Scenario

- **Low Renewables Scenario (LRS)**: Assumes that the growth of renewables will happen gradually and the state will not be able to achieve the renewable targets as declared.

Years	Wind Capacity (GW)	Solar Capacity (GW)	Peak Demand (GW)	Annual power demand (MU)	% Annual Demand met by RE
2020 (base line)	9.3	3.9	17.3	110,815	23%
2025	12.2	6.6	20.9	129,976	28%
2030	20.1	10.7	26.4	171,149	33%

Table 2: Low RE Scenario

Impacts of storage penetration is assessed in both scenarios considering its cost benefit analysis, its effects on system level cost and carbon dioxide emissions. It is observed that in both high and low renewables penetration scenarios, very high renewables spillage is observed in the state in the absence of enough export requirements and storage.

- **Minimum Renewables Scenario (MRS)**: A separate scenario assessing minimum RE addition levels in the state has also been analysed for the year 2030 which would result in lowest system level costs.

Years	Wind Capacity (GW)	Solar Capacity (GW)	Peak Demand (GW)	Annual power demand (MU)	% Annual Demand met by RE
2020 (base line)	9.3	3.9	17.3	110,815	23%
2025	12.2	6.6	20.9	129,976	28%
2030	12.0	7.5	26.4	171,149	25%

Table 3: Minimum RE Scenario

The results of various scenarios bring forward how inclusion of energy storage in the state's grid brings benefits in terms of lowering of system level costs, reduction of renewables spillage and reduction in carbon dioxide emissions. The model output suggests a gradual addition of energy storage in the grid based on grid requirements and economics of battery energy storage systems. The study showcases that it may be prudent to plan renewables addition based on a long-term strategy rather than to expand renewables just to meet targets. This would eventually result in reduction of spillage and optimum utilization of existing coal fleet available in the state. ***Figure 1*** and ***Figure 2*** highlights key outcomes from the model in terms of storage and system level costs for different scenarios.

As seen in ***Figure 1***, for minimum RE Scenario, 2.7 GW/ 5 GWh of BESS will be required to balance the grid, whereas for Low RE Scenario 3.9 GW/ 10 GWh of battery storage would be required. However, for High RE Scenario, requirement for long duration storage (6 hours) storage can also be witnessed based on the analysis. The requirement for storage in High RE Scenario is estimated as 7.2 GW/ 27 GWh by 2030.

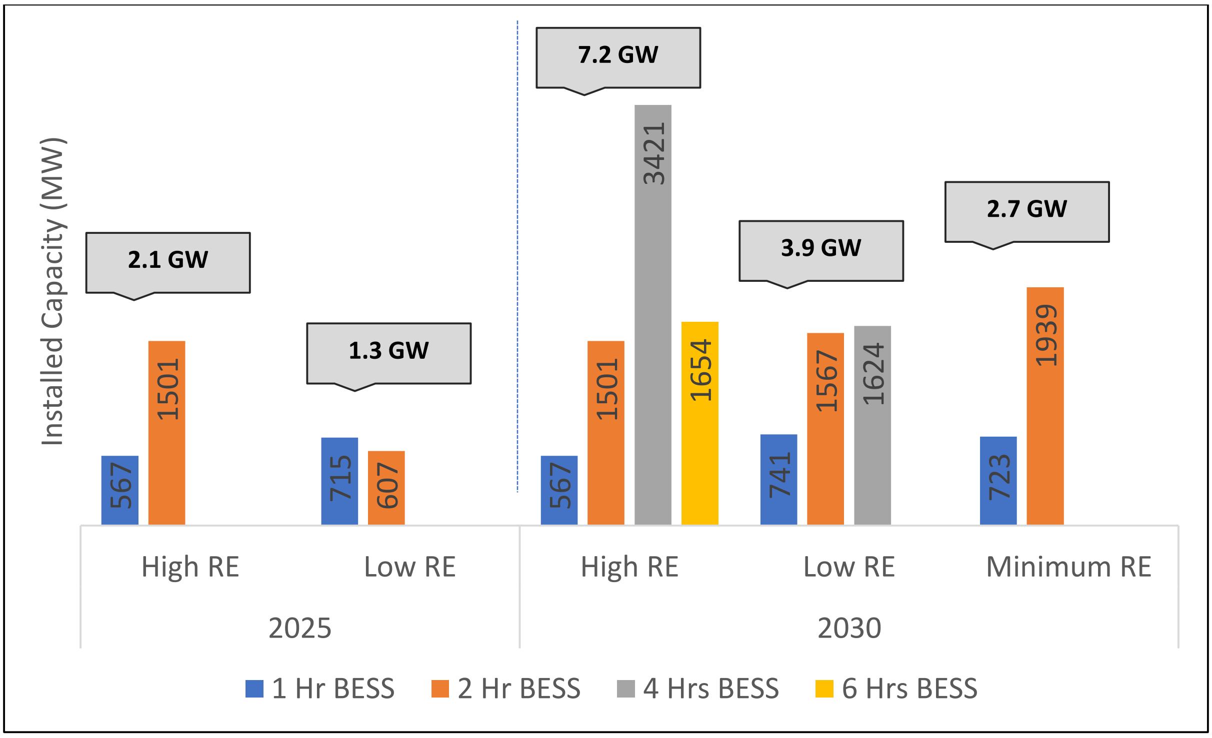


Figure 1: Cumulative ESS Capacity Requirement for TN in 2025 and 2030 (study output).

In terms of system level cost, the model projects savings by adding battery energy storage on the grid. The benefits are quite high for the HRS as shown in **Figure 2** whereby the benefits are more pronounced in terms of fixed cost as compared to variable cost. The same is discussed in detail in the subsequent sections of the report.

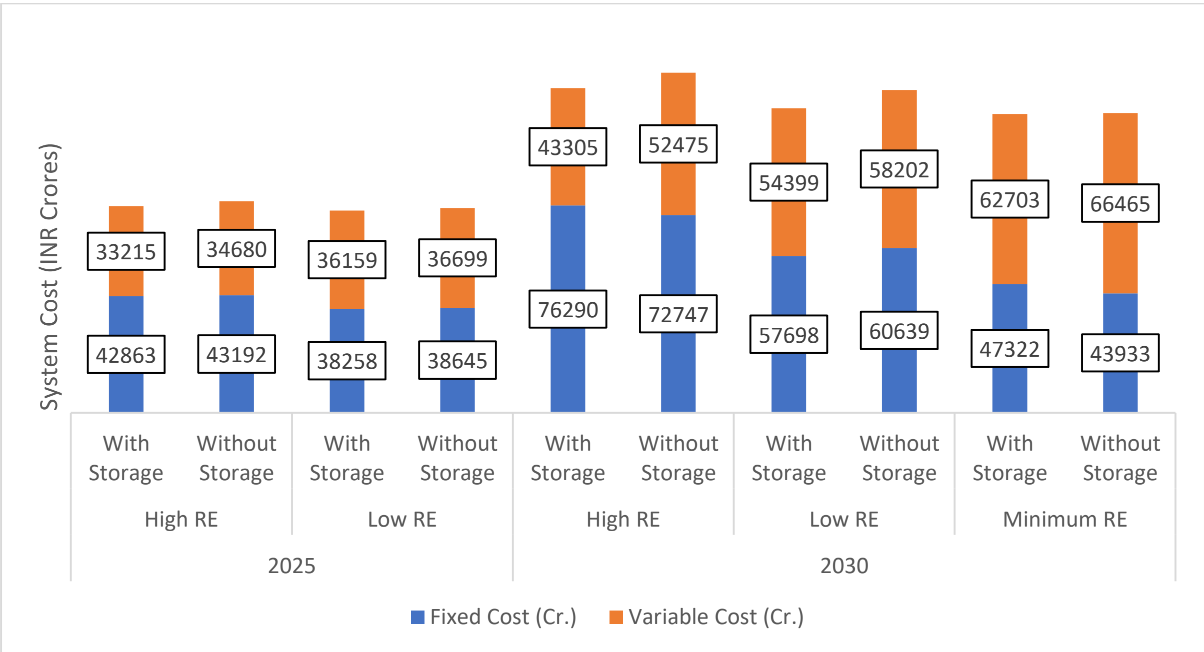
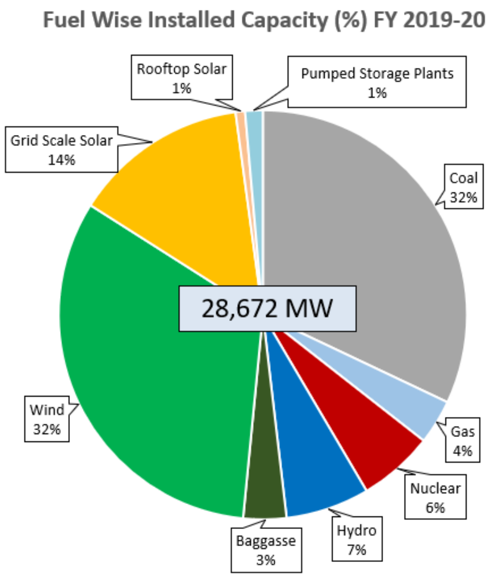


Figure 2: System Level Cost Benefits with Storage in various Scenarios.

2. Introduction

2.1 Tamil Nadu Power Generation Mix

Tamil Nadu has been at the forefront in terms of renewable energy penetration in India, leading in the total installed wind capacity in the country. The state enjoys a significant potential of wind 68.75 GW (at 120 meters.)[1] and solar 17.67 GW (MNRE, 2020). The state also has a potential of 31 GW[2] of offshore wind capacity in addition to the onshore wind potential. As on 31st March 2020, the total installed power capacity of Tamil Nadu was 28,672 MW (SRLDC, 2020) out of which 32% comes from coal while 47% of the installed capacity comes from renewables, with wind having the highest share at 32%. In terms of generation, the state recorded an annual generation of 1,10,967[3] MUs in FY2019-20 (SRLDC, 2020).



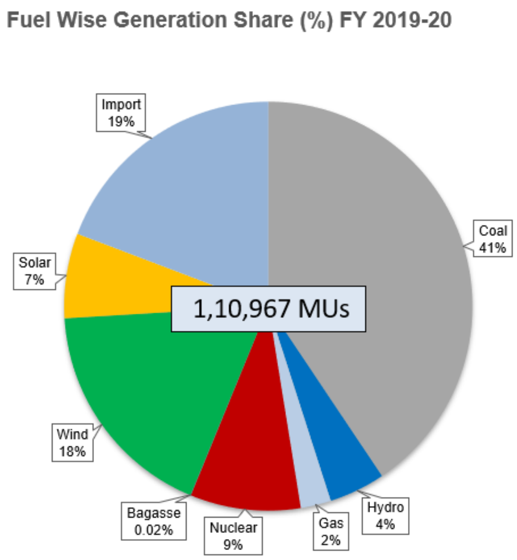


Figure 3: Power Installed Capacity and Generation Mix - 2019-20

In terms of generation, coal dominates the grid with 41% contribution as seen in ***Figure 3***, whereas renewables contribute to 23% of the generation in the state. As per the State Energy Policy Note 2020-21 (TN Policy Note, 2020), the state has a planned expansion of 14.6 GW for coal till 2030. As per National Electricity Plan 2018 (NEP 2018) (CEA, 2018), there is a suggested retirement of 3.1 GW of coal plants in the state due to non-availability of space to install FGD (Fuel Gas Desulphurizer) systems. The State Energy Policy Note 2020-21 also projects planned addition of 2.5 GW of nuclear capacity, 520 MW of hydro and 2.5 GW of gas by 2030. Also, as per the State Solar Policy 2019, the State Government plans to achieve 9 GW of solar PV capacity by 2023 (TN Solar Policy, 2019). TN does not have a specific target for wind capacity. Calculating the state's RE targets from the Central Government target of 175 GW of renewables by 2022 (MNRE, 2020), the state allocation of wind and solar capacity by 2022 comes out to be 11.9 GW and 8.8 GW[4] respectively.

The existing CAGR (2016-2019) for wind and solar in the state is 6% and 33% respectively. The year-on-year growth has specially been remarkable for solar, which stood at 1.1 GW in 2015-16, and stands cumulatively at 3.97 GW as of March 2020. The last two years, i.e., FY 2018-19 and FY 2019-20 saw

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[1] MNRE Annual Report 2019-20
[2] NIWE 2020 Annual Report
[3] SRLDC Mar 2020 Report
[4] MNRE Annual Report 2018-19, 2019-20

YOY growth of 35% and 54% for solar, respectively. The growth of wind though has been low, with the last two years seeing growth of 9% and 4% respectively. As on 31st March 2020, Tamil Nadu has been supplying 23% of its total energy demand through renewables. The generation share from RE has witnessed significant increase from 18% in FY2018-19 to 23% in FY2019-20.

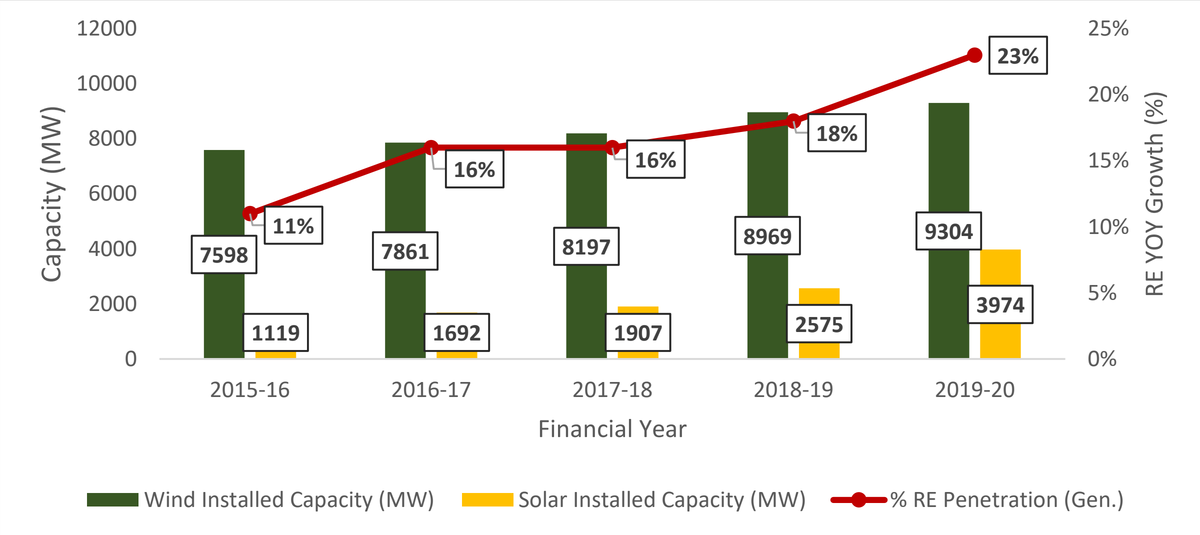


Figure 4: Renewables Growth in the State

Overall, the state power sector has been well balanced till now, although there have been instances of renewable curtailments, especially for wind, around 25% in peak seasons 2019-20 (Renewable Energy: Curtailment is a bane, 2020) and decreasing annual Plant Load Factor (PLF) trend for the coal fleet. This situation is expected to exacerbate further if storage is not integrated in the state's grid.

With increasing renewables in the state, there may be instances of increase in curtailment. Additionally, there are others challenges that need to be dealt with, namely:

- Inadequate Grid Availability: Given that Tamil Nadu is a RE-rich state, constraints are more pronounced during high generation periods (e.g.: monsoons)
- Coal fleet in the state may need to operate flexibly in order to absorb increase in renewable energy levels. This is a challenge as current coal plants may not be suitably designed for frequent switching operations (start-up and shut-down) and to provide fast ramp-up and ramp-down requirements (in general the ramping rate for coal plants is 1MW/min) (CEA, 2020)
- There is a planned addition of 14.6 GW of new coal plants in the state as per the state policy documents (TN Policy Note, 2020) in addition to plans for adding RE capacities in the state. Addition of such capacities may result in RE resources not being optimally utilized, thereby increasing overall system costs
- As per CEA LGBR Report 2020 (CEA, 2020), the state is expected to be both power and peak surplus in FY 2020-21. This could come across as a critical challenge for the utility in terms of load management.

The above challenges in view of future growth prospects of renewables in the state points towards the necessity to plan and execute all future additions in an integrated manner. The same also demands for requirement of including provisions for integration of energy storage in the grid to avoid curtailment and reduce further thermal plant additions thereby saving system costs and reducing emissions.

2.2 Scope and Objective of Analysis

With the commitment to move towards a greener grid and considering future demand growth prospects, the study analyses how to make renewables more effective by addition of storage in the grid. The present study is an effort to analyse the scope of Battery Energy Storage System (BESS) for Tamil Nadu grid. The study analyses the capacity and hours of storage required under different RE penetration scenarios. A detailed analysis using production cost modelling exercise is carried out to assess storage levels for Tamil Nadu grid in 2025 and 2030. The analysis also evaluates the benefit that storage brings in avoiding RE spillage, deferring investments in coal, and achieving environmental benefits by reducing CO_2 emissions. At a local level, T&D deferral cost benefit analysis is included in the overall system benefits to arrive at financial benefits at a project level.

2.3 Energy Storage – Applications, benefits, and trends

Energy storage finds application in various areas of grid applications - frequency regulations, flexible ramping, black start support, and investment deferral for the T&D sector. The benefit of storage particularly is prominent in case of renewable integration since it makes renewables much more reliable and firmer by reducing the need for curtailment. It helps in load and peak shifting, making the renewables supply curve much smoother by absorbing any excess generation and discharging the same during periods of low resource availability and overall better grid balancing.

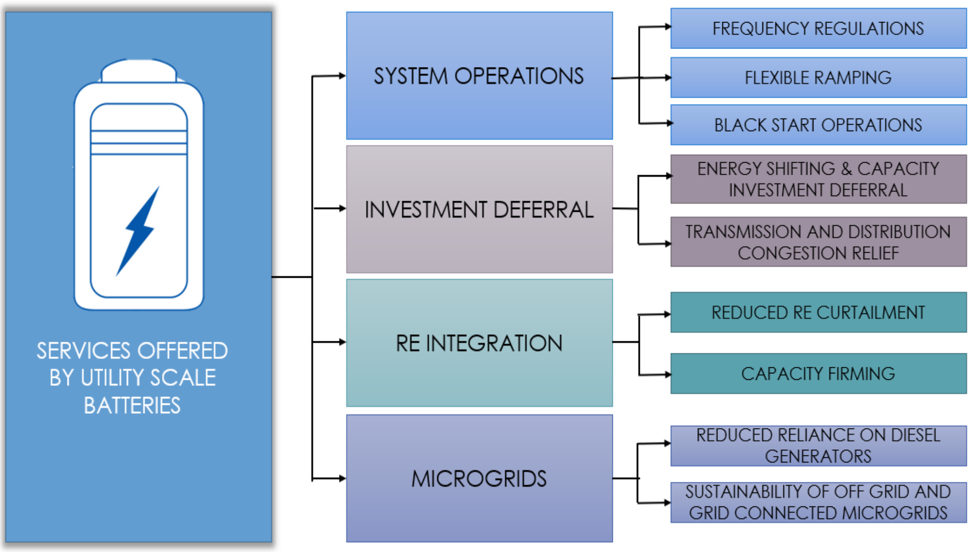


Figure 5: BESS Utility Scale Applications

Among various battery storage technologies existing today, lithium-ion has found most applications due to the exponential drop in costs and the ability to serve different requirements including 4 hours or less than 4 hours applications. Over the last one-decade lithium-ion cells have seen a price drop of 87%. As of 2020, it stands at USD 110/kWh [5]. Although BESS price is still considered over USD 200/kWh for many of the applications, price of Li-ion cells is expected to drop to USD 100/kWh by 2022 (BNEF, 2019).

[5] CES Analysis

In this study, the analysis focusses on evaluating battery storage system requirements for Tamil Nadu, particularly Lithium-ion (Li-ion) which are more commercially viable[6]. ***Figure* 5** illustrates the various applications that BESS finds at grid-integration level. Tamil Nadu already has a pumped hydro storage plant (Kadamparai – 400MW) in the state which has been considered in the production cost analysis.

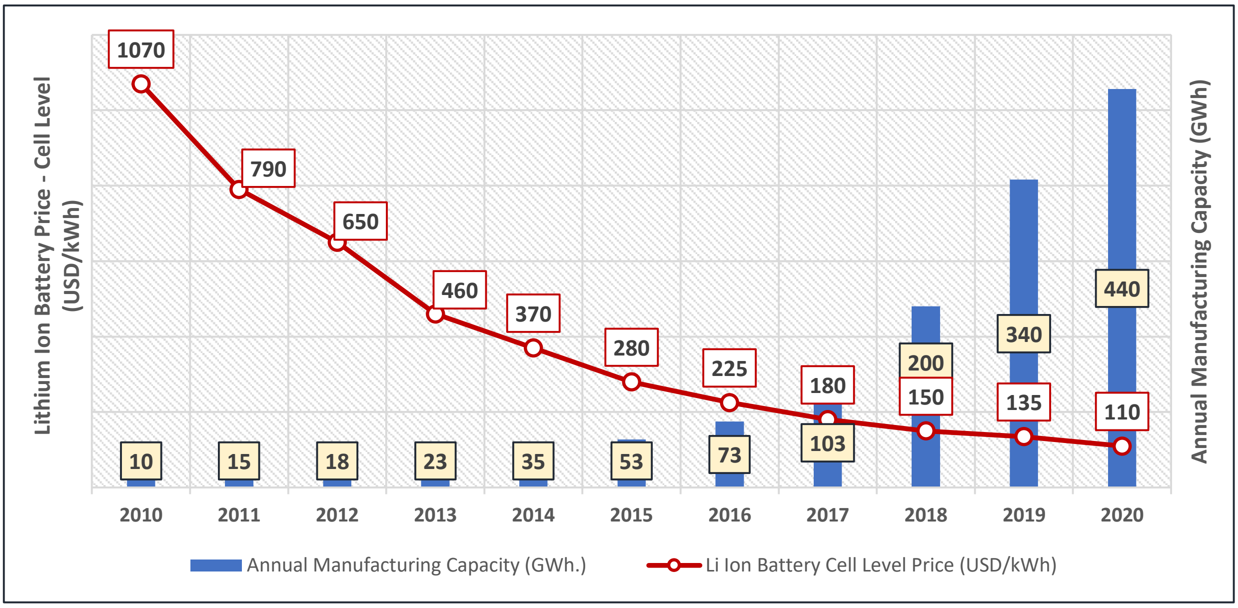


Figure 6: Li-Ion Cell Level Price Trend

Over time the technological improvements that energy storage has seen along with the drop in battery cell prices, as shown in ***Figure 6***, have made energy storage competitive in comparison to other technologies (LAZARD, 2020). As on date RE + battery storage is already more economical than newly built coal or gas-peaker plants (LAZARD, 2020). Considering the recent examples, the coal plant Power Purchase Agreement (PPA) which was signed by the Madhya Pradesh Government and Adani has a tariff of INR 4.8/kWh (Financial Express, 2020) with escalation over the next 25 years. On the other hand, the 1.2 GW SECI peak power tender (RE Hybrid with ESS) was won at an average cost of INR 4.3/kWh including storage of 6 hours. More recently, the 400 MW RTC tender was won by Renew Power at a base year tariff of INR 2.9/kWh and an LCOE of INR 3.6/kWh[7] (SECI, 2020).

Looking at global trends, the PPA prices for solar with storage tenders in US saw a 16%[8] fall in tariff in just one year between 2018 and 2019. CES analysis shows that the blended cost of renewables with storage (4 hours) will drop to around INR 3/kWh by 2027 (Alliance, India Energy Storage, 2020). With more deployment of renewable projects coupled with storage, it is envisaged that the price of battery storage technologies, especially Li-ion will further drop considering technological improvements and scaling up of manufacturing facilities in India and across the globe.

[6] CES Analysis
[7] SECI RTC Tender Result
[8] USA Solar + Storage Monitor – ESA – June 2020

3. System Analysis

3.1 Introduction to Production Cost Model used

A production cost model solves the optimal power flow formulation which takes generation limits and operational constraints such as ramp rates and transmission limits into consideration while solving for the least cost optimal dispatch. Using the model, one can simulate dispatch in different scenarios and address questions related to operation, capacity adequacy, curtailment, emission etc. The model allows us to look at various operational aspects of the system simultaneously and evaluate combined economic impacts of decisions. In this study, a representative model has been developed for the state of Tamil Nadu, using an open-source power system modeling framework PyPSA (Python for Power System Analysis). The model developed using PyPSA[9] minimizes the total system costs for the simulation period considering the system operating constraints. Models are simulated at hourly resolution for 2025 and 2030 to assess BESS requirements for low RE, high RE and minimum RE penetration levels in Tamil Nadu.

3.2 Introduction to CoMETS

CoMETS (Comprehensive Market Evaluation Tools for Storage), a tool developed by Customized Energy Solutions is used to evaluate and optimize energy storage for various large-scale grid connected as well as small scale behind-the-meter applications.

For this analysis, the tool evaluates economics of an individual storage project, if commissioned. The tool uses insights from the production cost system level analysis to drive the economics. The process flow is explained in the ***Figure 7*** and ***Figure 8.***

The CoMETS model works on the output as provided by the production cost model. The model analyzes the output in terms of power, energy, efficiency, State of Charge (SOC), CAPEX and OPEX requirement. For a long-term project, benefits for applications (such as energy arbitrage, peak shaving and RE shifting) are initially calculated on a per MW basis and then scaled appropriately through time series dispatch.

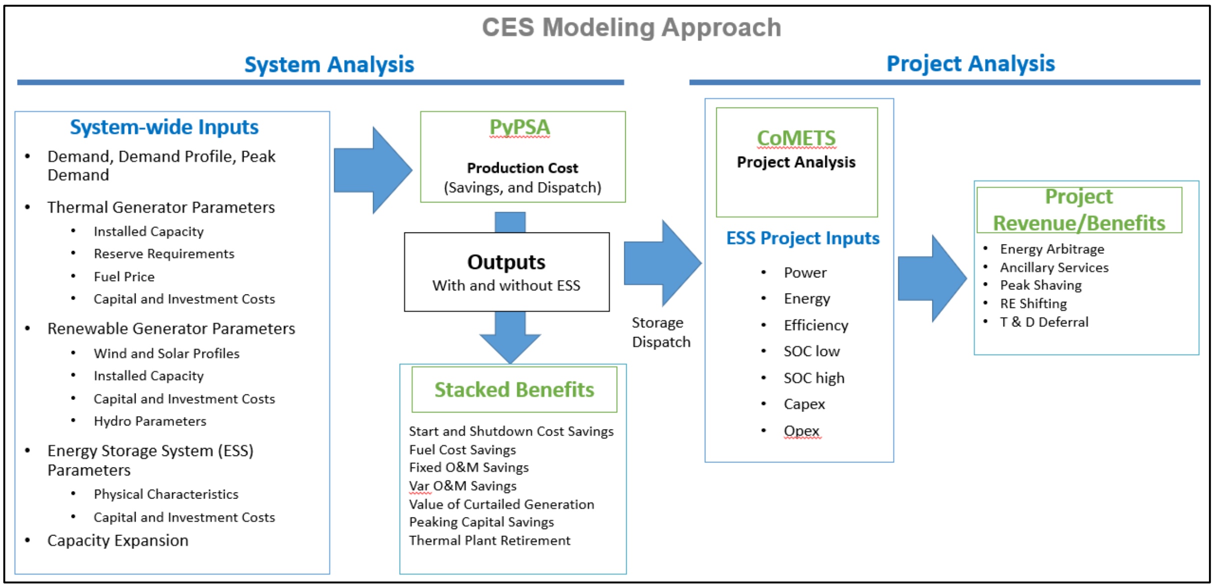


Figure 7: CES Modeling Approach – Methodology

[9] PyPSA was published in 2018 by T. Brown et.al. and is currently being maintained by the Energy Modelling group at Karlsruhe Institute for Technology, Germany.

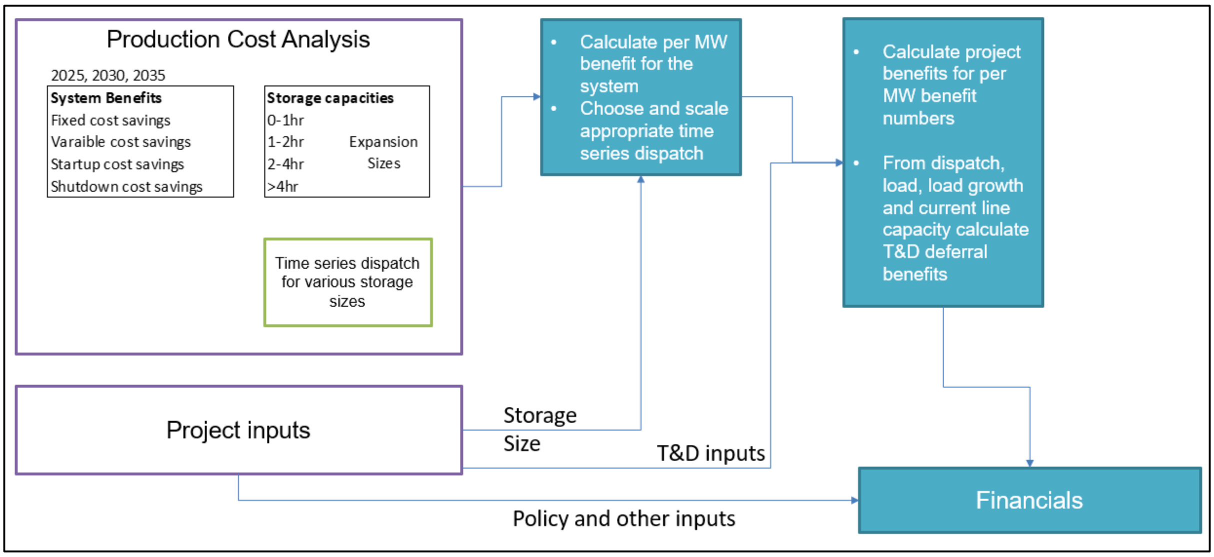


Figure 8: Production Cost Analysis – Process

3.3 Approach and Methodology

For evaluating the role of storage in Tamil Nadu's grid, the state is considered as a single entity. Dispatch from different generating plants is considered to fulfil the state's demand at an hourly resolution.

Modelling process: State level system data was collected and consolidated in an appropriate format which was then given as input to the PyPSA model. All necessary system constraints were defined in the model along with various scenarios for dispatch of resources. Dispatch obtained in each of these scenarios were evaluated individually to calculate total system operating cost, possibilities of renewable curtailment, total CO_2 emissions, storage sizing along with SOC, charge and discharge cycles. Based on these parameters, benefits of different investments and operation strategies were evaluated.

In the present study, a single node PyPSA-based production cost model was developed without any transmission constraints. However, energy losses due to these constraints are incorporated in the overall demand. Other aspects of the system such as supply capacity, hourly demand, ramping constraints, renewable resource availability, variable and fixed costs and policy targets were provided exogenously as inputs to the model. The model represents the power system at the resolution as defined in the input data. The physical limitations of the grid are modelled as constraints limiting the generation capacity to installed capacity, operation level to technical minimum levels, renewable sources-based generation to resource availability, change of dispatch level between time steps to corresponding ramping rates. Since the objective of the study was also to determine cost and benefit of investment in storage technologies, the model is run like a capacity expansion model without evaluating unit commitment and transmission network constraints.

Using this model, three scenarios; HRS, LRS and MRS were evaluated at two different time horizons, 2025 and 2030. System-level findings (covering generation capacities in megawatts, total generation in MUs, generation shares and capacity utilization factors of different sources, total emission levels, total system costs) were observed for each scenario, compared, and analysed to assess the benefits of addition of storage into Tamil Nadu's grid.

3.4 Assumptions and Limitations

Assumptions taken in the model and the limitations are detailed below:

- **Load Profile:** The demand curve of the state was scaled across the years and the current profile was assumed to continue for 2025 and 2030-time horizon. The annual load demand and peak-met details are further detailed in ***3.5.1 Load Projection***.
- **Transmission:** Single node model was considered for the study. Intra state transmission constraints are not taken into consideration.
- **System Imports and Exports:** Only long-term system imports have been considered in this study. In FY 2019-20, as exports were minimal, system exports were not considered. For future years as well, the model has not considered system exports.
- **Hydro:** Monthly maximum generation levels are considered (2019-20 levels) for hydro.
- **Generation capacity:** Coal, nuclear, and gas capacities are considered at individual plant levels in the model. For Central Generating Station (CGS) plants, allocated capacities for TN are considered.
- Solar and wind generation profiles are considered at hourly profiles intervals based on typical monthly profiles in the power system operation reports of SRLDC, whereas bagasse, hydro are represented as cumulative generations.
- For future scenarios in 2025 and 2030, the model is run in a capacity expansion mode for renewables, considering their annualized capex. One of the limitations of PyPSA is that PyPSA is not compatible to execute unit commitments and investment optimization simultaneously.
- Technical operational minimum for coal plants is taken as 55% for coal (CEA, 2020). Auxiliary consumption of 10% is considered for coal and nuclear as per industry practice. An additional decrease of 10% availability is considered for coal and 15% for nuclear on an annual basis for annual maintenance.
- **Plant Fixed and Variable Costs:** A 5% escalation YOY on variable cost is considered for coal plants, based on tariff orders. For all new plants, the costs have been considered as laid in the policy document (TN Policy Note, 2020). Such costs are annuitized at 10% discount rate over the project lifetime.

3.5 Defining Model Scenarios

Two sample years have been considered for this study: 2025 and 2030. In 2025, the model is run for two scenarios i.e., the high RE Scenario (HRS) and low RE Scenario (LRS). As previously explained, in HRS, it is assumed that the state will be achieving its RE targets within time, whereas in the LRS it is assumed that the state will not be able to achieve the RE targets within timelines. The assumptions and targets considered in both these scenarios have been explained in detail in section ***3.5.2 Renewable Supply Scenarios***. The model inputs for the year 2025 is calculated as per the State Energy Policy Note 2020-21.

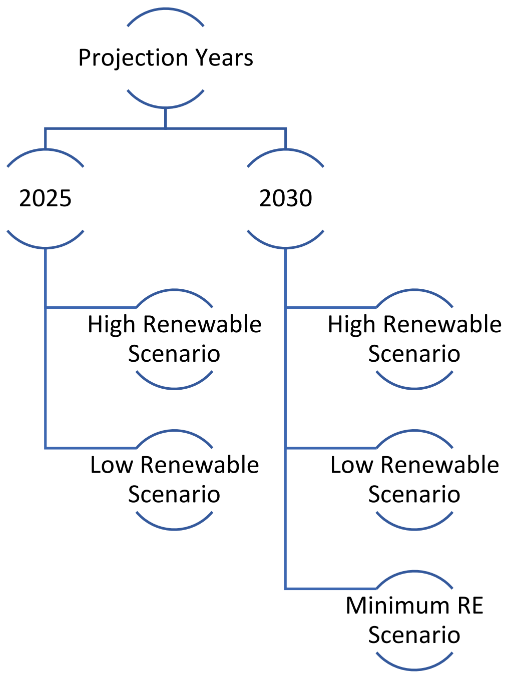


Figure 9: Scenarios

The inputs for 2030 were taken from the model outputs of the year 2025. In 2030, the model was run for both high RE and low RE scenarios. Additionally, another scenario to evaluate minimum RE scenario (MRS) was evaluated. The inputs to this scenario were taken from the outputs of the Low RE Scenario of 2025. In this scenario, both coal and RE capacities were kept flexible to assess storage needs based on minimum system level cost criteria. A snapshot of the scenarios is shown above in ***Figure 9.***

3.5.1 Load Projection

For estimating peak demand and aggregate demand for future years, the study has considered load growth in line with Central Electricity Authority (CEA) Long-term Electricity Demand Forecasting report (Central Electricity Authority, 2019). The report segregates load demand for the present decade into two sections i.e., Financial Year (FY) 2022-2027 and FY 2027-2037 as detailed in ***Table 4***.

	FY22-FY27	***FY28-FY30***
Demand in MUs	5.69%	5.65%
Peak Demand MW	4.84%	4.80%
Growth rate for Actual Load in FY 21 due to COVID	-6%	
Growth rate for Peak demand Due to COVID FY 21	0%	

Table 4: Demand CAGR Projections

The CEA report further classifies the growth under two scenarios, optimistic and pessimistic load growth scenarios. In the optimistic growth scenario, it has considered a CAGR of 5.69% aggregated demand growth in between 2022-2027 and thereafter 5.65% between 2028-2030. As for peak demand, the report has considered a CAGR of 4.84% for peak demand between 2022-2027 and thereafter 4.8% between 2028-2030.

In the present study, optimistic growth rate is considered. The YOY growth for both peak and aggregated demand is shown in ***Figure 10***. The study has also considered a short-term impact of COVID-19 on the load growth for the period 2020-2021. It is assumed that there will be a 6% downward impact on growth in FY 2020-21 in terms of aggregate demand and no growth in peak for this period. Thereafter, the growth is assumed to be in accordance with the long term forecast as specified in the CEA report. Thus, the aggregated load demand in 2030 is projected to be 171,149 MUs and the maximum peak demand is expected to increase to 26.42 GW from 17.29 GW as seen in FY2019-20.

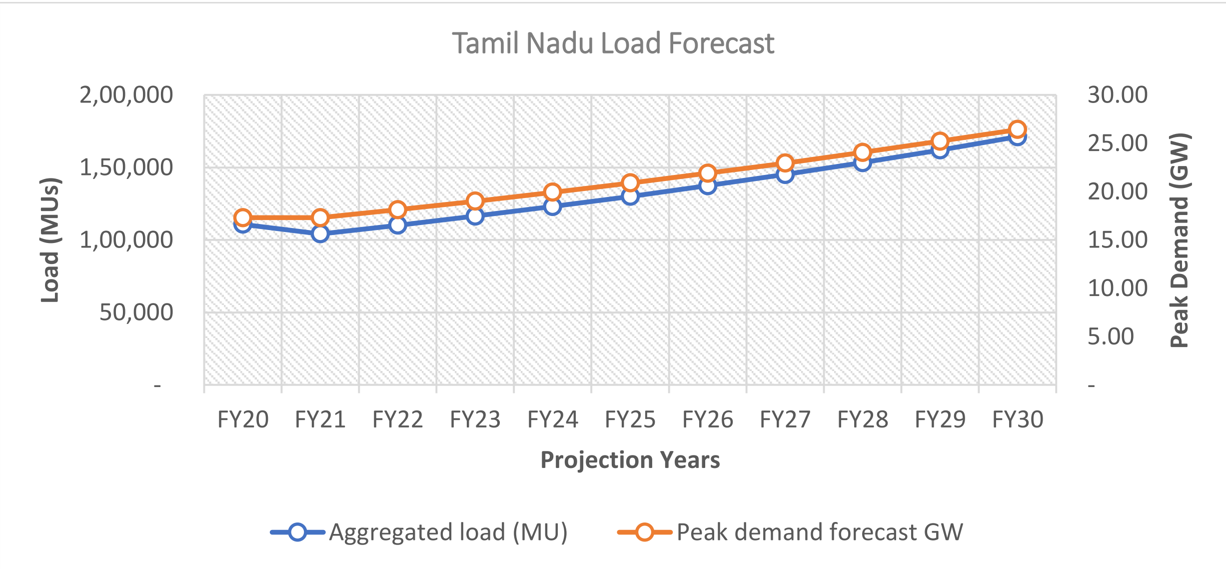


Figure 10: TN Load Growth Trend

3.5.2 Renewable Supply Scenarios

There are two RE scenarios that have been considered in this report as discussed in ***section 3.5.*** The following section elaborates the assumptions in detail.

3.5.2.1 High RE Scenario

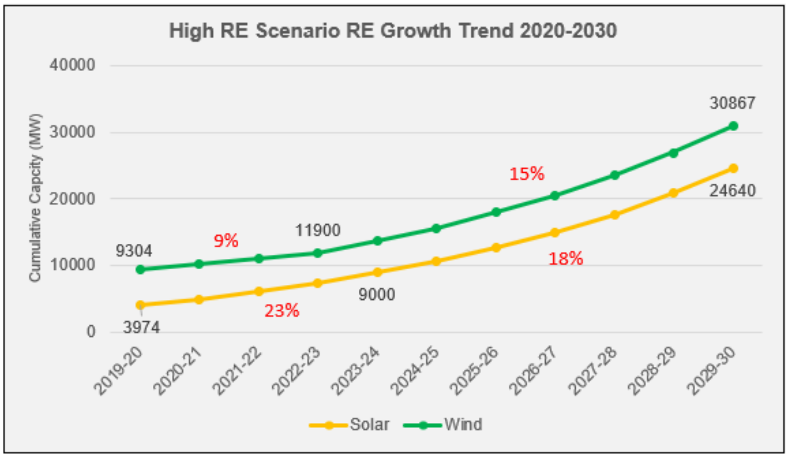


Figure 11: High RE Scenario Projections

Solar

In the short term, CAGR from 2020 to 2023 is considered as 23% keeping in mind that the state will achieve its solar policy target of 9 GW by 2023 (TN Solar Policy, 2019). The total installed capacity of solar assumed in 2030 is 24.6 GW (CAGR from 2024 to 2030 is considered as 18%, assuming that the state will be achieving the state allotted target as per CEA by 2030). This is 39% above the state potential of 17.67 GW (MNRE, 2020).

Solar 2023 (MW)	Solar CAGR 2020 - 2023	Solar 2030 (MW)	Solar CAGR 2024 - 2030
9,000	23%	24,640	18%

Wind

It is assumed that wind will attain its 2022 state allocated target as per CEA of 11,900 MW in High RE Scenario (CEA, 2020). To attain this, therefore a CAGR of 9% is considered for wind.

It is assumed that wind will match up to its 2030 target as set by CEA (28 GW) (CEA, 2020). Over and above, there will be a small penetration of offshore wind. The state potential is 31 GW (NIWE, 2020). The model considers a 10% penetration by 2030 of the total potential. Thus, the total capacity of wind in TN by 2030 is assumed to be 30.9 GW. The CAGR considered from 2023 to 2030 is 15%.

Wind 2022 MW	Wind CAGR 2020 - 2022	Wind 2030 MW	Wind CAGR 2023 - 2030
11,900	9%	30,867	15%

3.5.2.2 Low RE Scenario

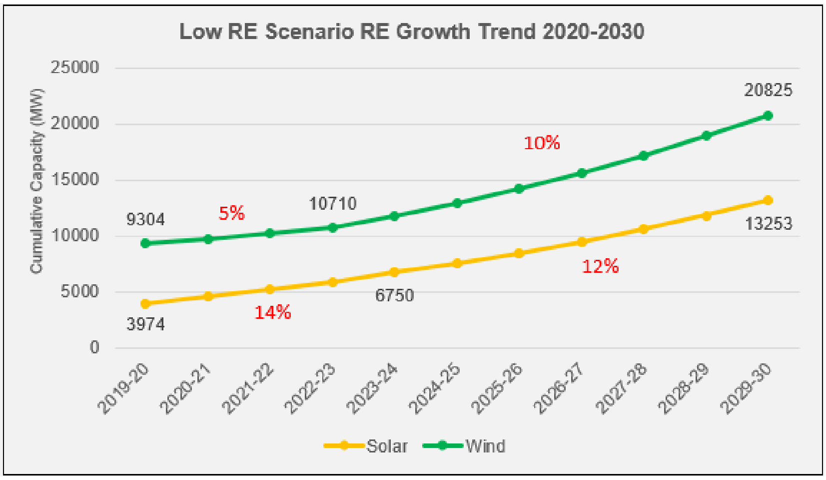


Figure 12: Low RE Scenario Projections

Solar

In low RE scenario, it is assumed that the state will be able to achieve 75% of its 9 GW target by 2023. This would be mainly due to disruptions caused by COVID-19. Thus, the CAGR till 2023 for the state is taken as 14%.

From 2024 to 2030, a CAGR of 12% is considered assuming that the state will be able to achieve 75% of its potential capacity (17.67 GW) by 2030.

Solar 2023 MW	Solar CAGR 2020 - 2023	Solar 2030 MW	Solar CAGR 2024 - 2030
6,750	14%	13,253	12%

Wind

For the low RE scenario, a CAGR of 5% is considered in line with the existing CAGR of the past 5 years and this is also in line with the state attaining 90% of its allotted target of 11,900 MW by 2022.

For long term i.e., 2023 to 2030, a CAGR of 10% is considered assuming that the state will attain 75% of its CEA target in 2030.

Wind 2022 (MW)	Wind CAGR 2020 - 2022	Wind 2030 (MW)	Wind CAGR 2023 - 2030
10,710	5%	20,825	10%

3.5.2.3. Roof Top Solar Projections

Rooftop penetration is considered as 40% of the total solar capacity installation year-on-year. We assumed penetration of 70% of the total rooftop generation and hence netted out of the load. Remaining 30% is added to the grid.

	High RE			Low RE		
Year	Cumulative Capacity (MW)	Load Reduction (MW)	Dispatch Inclusion (MW)	Cumulative Capacity (MW)	Load Reduction (MW)	Dispatch Inclusion (MW)
2019	214	150	64	214	150	64
2022	1017	712	305	696	487	209
2025	2882	2018	865	1646	1152	494
2030	8480	5936	2544	3925	2748	1178

Table 5: Rooftop Projections

3.5.3 Import and Export

System exports are not modelled in this analysis. Long term system imports are considered in the model.

4. Outputs of the model

4.1 Year 2025

4.1.1. High RE Scenario (HRS)

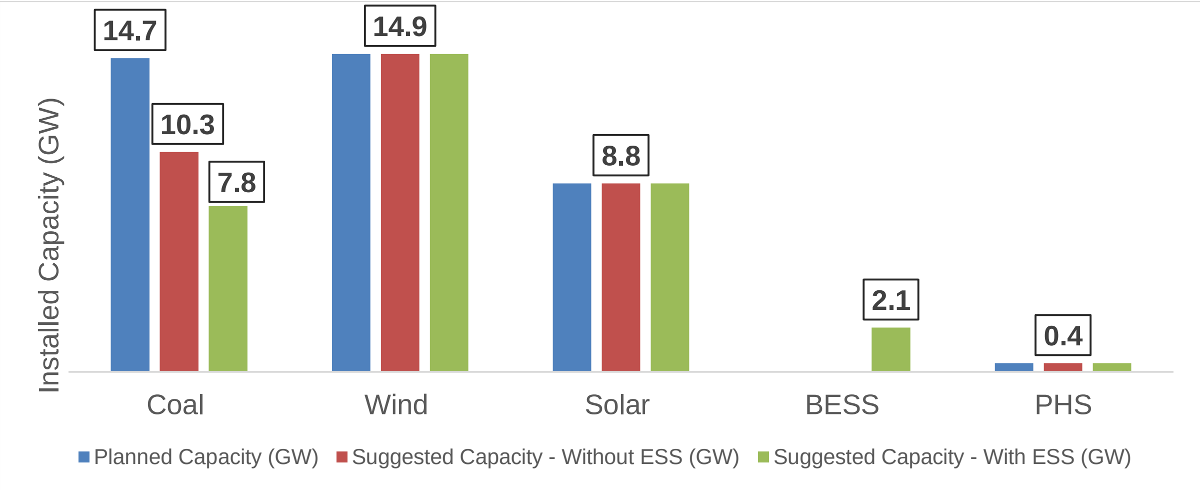


Figure 13: Installed Capacity - HRS - 2025

Capacity Addition

In the high RE Scenario of 2025, a planned addition of 5.7 GW coal capacity is considered between FY20 to FY25 as per the State Energy Policy Document 2020-21 and retirement of 170 MW of coal capacity based on recommendations as provided in National Electricity Plan 2018 (CEA, 2018).

Input	Wind Capacity (GW)	Solar Capacity (GW)	Peak Demand (GW)	Annual Power Demand (MU)
2020 (base line)	9.3	3.9	17.3	110,815
2025	14.9	8.8	20.9	129,976

Table 6: 2025 High RE Scenario

The model projects that with 55% technical minimum in place for coal plants as per CEA, there can be around 4.4 GW of coal capacity which may remain unutilized. With penetration of storage in the state's grid (**2.1 GW**) the quantum of unutilized capacity of coal in the grid increases to 6.9 GW. Thus, the resultant capacity of coal stands at 10.3 GW and 7.8 GW in 'without storage' and 'with storage cases', respectively. The unutilized coal fleet mainly includes such thermal plants which are nearing end of PPA life and coal units which have higher generation cost. Renewables penetration in high RE scenario considers wind at 14.9 GW and solar at 8.8 GW. The other fuel source expansions are as per the State Energy Policy document (TN Policy Note, 2020), with Gas, Hydro, Nuclear and Bagasse capacities at 2.5 GW, 2.4 GW, 2.5 GW and 0.8 GW respectively.

Output	With Storage Case			Without Storage Case		
	GW	% Energy	PLF (%)	GW	% Energy	PLF (%)
Coal	7.8	33.5	67	10.3	43.1	64
Wind	14.9	22.5	24	14.9	20.7	21
Solar	8.8	10.7	19	8.8	8.8	15

Table 7: High RE - 2025 - Generation Mix

Storage Penetration

In HRS, the model projects an inclusion of 2.1 GW of storage - with 0.6 GW of 1-hour capacity and 1.5 GW of 2-hour capacity. This is further detailed in ***section 4.1.4***. The model considers 400 MW of pumped hydro capacity present in the grid, with no further expansion.

Renewable Spillage

It is observed from the model that there is a significant increase in the percentage of spillage of RE. The model projects that there could be possibility of higher spillage of solar (32% in 'without storage' and 16% in 'with storage' cases). Wind spillage does not see much change from current reported values (25% in 2019-20) (Renewable Energy: Curtailment is a bane, 2020). The model does not account for system exports, nevertheless some part of this spillage could be absorbed if the system exports are allowed in the future.

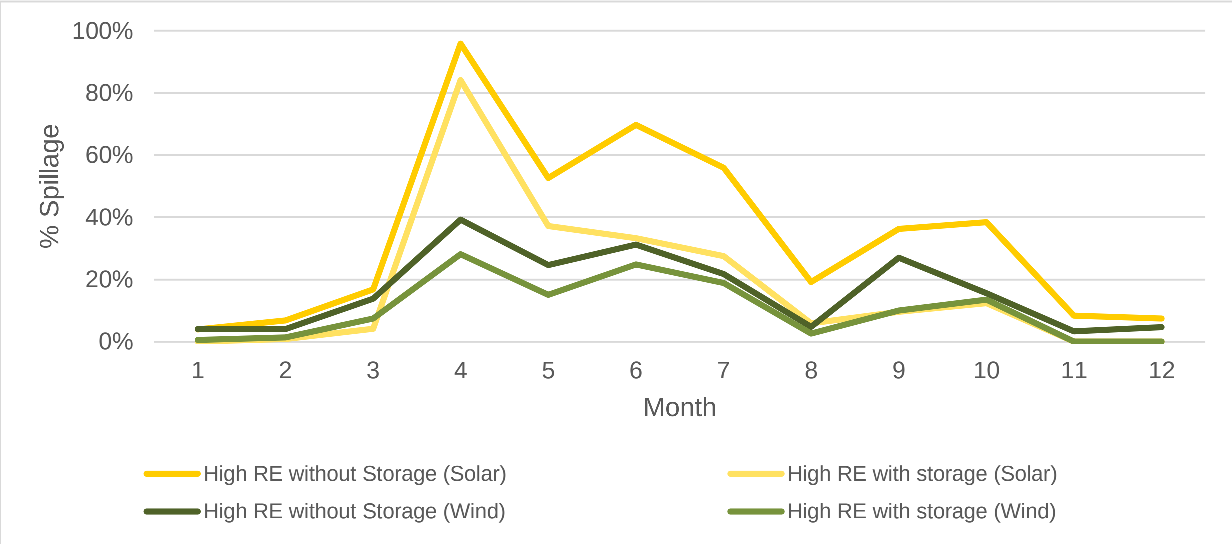


Figure 14: RE Spillage Trend - 2025 - High RE

Resource Utilization

In terms of utilization of resources, coal utilization improves from 64% to 67% with storage inclusion while coal's generation share reduces from 43% to 34%. This is partly explained by the increasing generation share of renewables, 33% (with storage) from present 23% (2019-20). The generation share of renewables increases by 4% due to inclusion of storage resulting in decrease of RE spillage. RE utilization is assumed to remain the same at 2019-20 level (24% for wind and 19% for solar). A slight improvement in PLF of gas is observed in this scenario (57% to 63%). Short term imports remain in the grid in 2025 and constitutes 5.6% in the generation mix.

System Level Costs - Benefits

This scenario sees a saving on the system level cost of INR 1,800 crore. It is observed that there is more reduction in variable costs due to reduced utilisation of coal capacity in the grid. The total system level cost in the high RE scenario with inclusion of 2.1 GW of storage is INR 76,100 crore against INR 77,900 crore when there is presence of more coal in the grid. The system also projects a saving of 2 million tons of CO_2 with inclusion of storage in the grid.

4.1.2 Low RE Scenario (LRS)

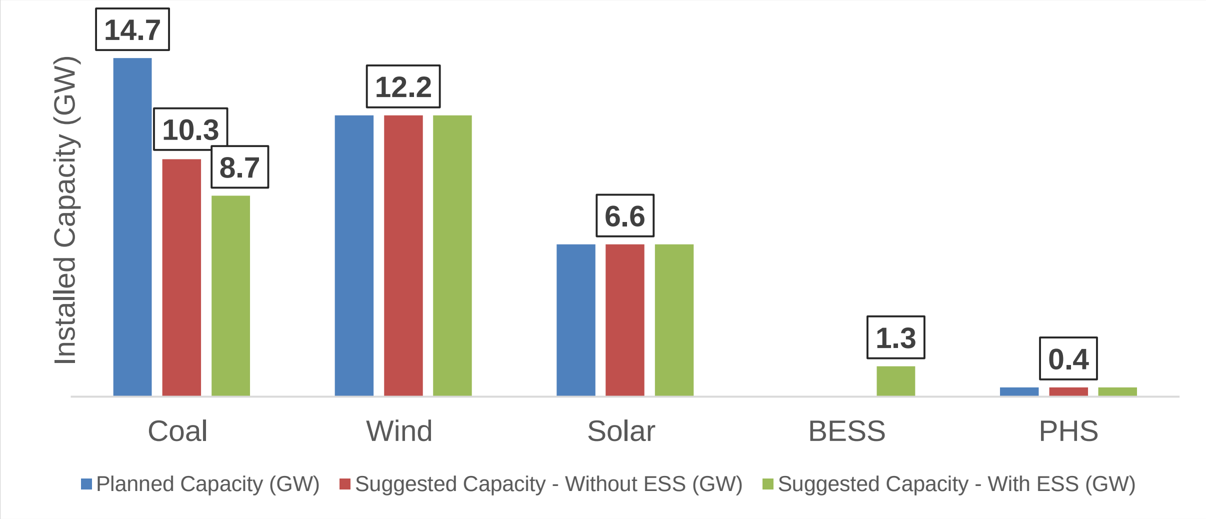


Figure 15: Installed Capacity - 2025 - Low RE

Capacity Addition

In the low RE scenario of 2025, a planned addition of 5.7 GW coal capacity is considered as per the State Energy Policy Document 2020-21 and retirement of 170 MW of Coal capacity as per NEP 2018 plan (CEA, 2018).

Input	Wind Capacity (GW)	Solar Capacity (GW)	Peak Demand (GW)	Annual power demand (MU)
2020 (base line)	9.3	3.9	17.3	110,815
2025	12.2	6.6	20.9	129,976

Table 8: 2025 Low RE Scenario

The model projects that with 55% technical minimum for coal plants (as per CEA), there can be around 4.4 GW of coal capacity which may remain unutilized. With penetration of storage in the state's grid **(1.3 GW)** the quantum of unutilized capacity of coal in the grid increases to 6 GW. Thus, the resultant capacity of coal stands at 10.3 GW and 8.7 GW in 'without storage' and 'with storage' cases, respectively. The unutilized coal fleet mainly includes thermal plants which are nearing end of PPA life and coal units which have higher generation cost. Renewables penetration in low RE scenario considers wind at 12.2 GW and solar at 6.6 GW. The other fuel source expansions are as per the State Energy Policy document (TN Policy Note, 2020) with capacities of gas, hydro, nuclear and bagasse at 2.5 GW, 2.4 GW, 2.5 GW and 0.8 GW respectively.

Output	With Storage Case			Without Storage Case		
	GW	% Energy	PLF (%)	GW	% Energy	PLF (%)
Coal	8.7	38	69	10.3	44	66
Wind	12.2	20	25	12.2	19	24
Solar	6.6	8.4	20	6.6	7.9	19

Table 9: Low RE - 2025 - Generation Mix

Storage Penetration

In the low RE scenario, the model projects inclusion of 1.3 GW of storage - with 0.7 GW of 1-hour capacity and 0.6 GW of 2-hour capacity (further detailed in ***section 4.1.4 Overall BESS***

***Penetration*).**The duration in Low RE Scenario is more in 1-hour duration against that in the High RE Scenario. The model retains 400 MW of pumped hydro capacity in the grid, with no expansion.

Renewable Spillage

We observe from the model that there is a significant increase in the percentage of spillage observed for RE. The model projects higher spillage of solar (18% in ‘without storage’ case and 12% ‘with storage’ case). Wind spillage is a bit on the lower side (15% in ‘without storage’ case which reduces to 10% ‘with storage’ case). As the model does not account for system exports, some part of this spillage could be absorbed if system exports are allowed in the future.

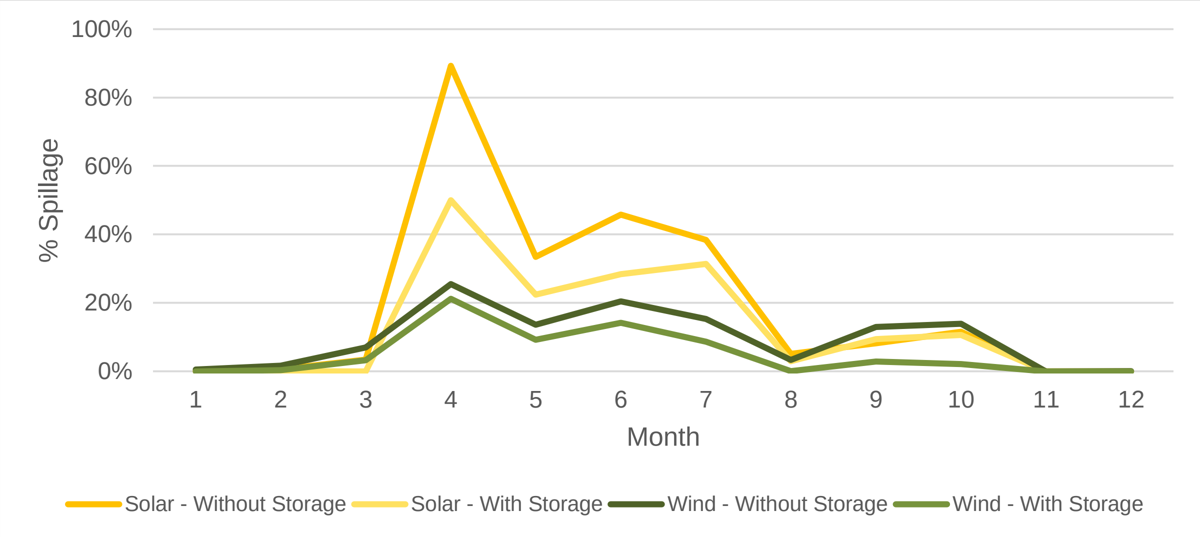


Figure 16: RE Spillage Trend - Low RE - 2025

Resource Utilization

In terms of utilization of resources, coal utilization improves from 66% to 69% with storage inclusion while coal’s generation share reduces from 44% to 38%. This is partly explained by the increasing generation share of renewables; 28% (with storage) from present 24% (2019-20). RE utilization has been assumed to be at 25% for wind and 20% for solar. Due to more utilization as a flexible resource a slight improvement in PLF of gas is observed in this scenario (63% to 67%). Short term imports remain in the grid in 2025 and constitute 5% in the generation mix.

System Level Cost – Benefits

This scenario sees a saving in the system level cost of INR 900 crore. It is observed that there is more reduction in variable costs due to an increased amount of coal capacity not being utilized in the grid. The total system level cost in the low RE scenario with inclusion of 1.3 GW of storage is INR 74,500 crore against INR 75,400 crore when there is presence of more coal in the grid. The system also projects a saving of 1 million tons of CO_2 with inclusion of storage in the grid.

4.1.3. Overall Seasonal Dispatch Profile

The seasonal load profiles for High RE and Low RE Scenarios with storage are shown in ***Figure 17*** and ***Figure 18***. An effort has been made to understand the seasonal variation, thus profiles of January, May, July, and October were selected and studied. Months of January and October are months with lower RE availability in the state; it is observed that the role of storage in these months is more focused on providing a buffer against short term variations of solar and wind during the day and will help in managing evening peaks. The discharge duration of storage in these months are shorter and the energy requirement from storage is also less when compared to high RE resource months. In the months of May and July when RE resource availability in the state is high, storage helps by playing a more critical role by absorbing excess RE (which would be potentially curtailed with no storage in the grid). Hence, it can be seen that during the daytime when load requirement is low and RE generation (wind and solar combined) is at its peak, excess RE is used to charge the batteries and the same is discharged during the evening hours when demand increases and solar generation plummets. The profile also indicates that coal, nuclear, and gas helps in providing the base load. Utilization of coal remains low in high RE months as it is restricted to technical minimum (55% as per CEA) while coal is more flexible in low RE months. Similar pattern was observed in Low RE scenario too, but with storage having lesser duration and capacities.

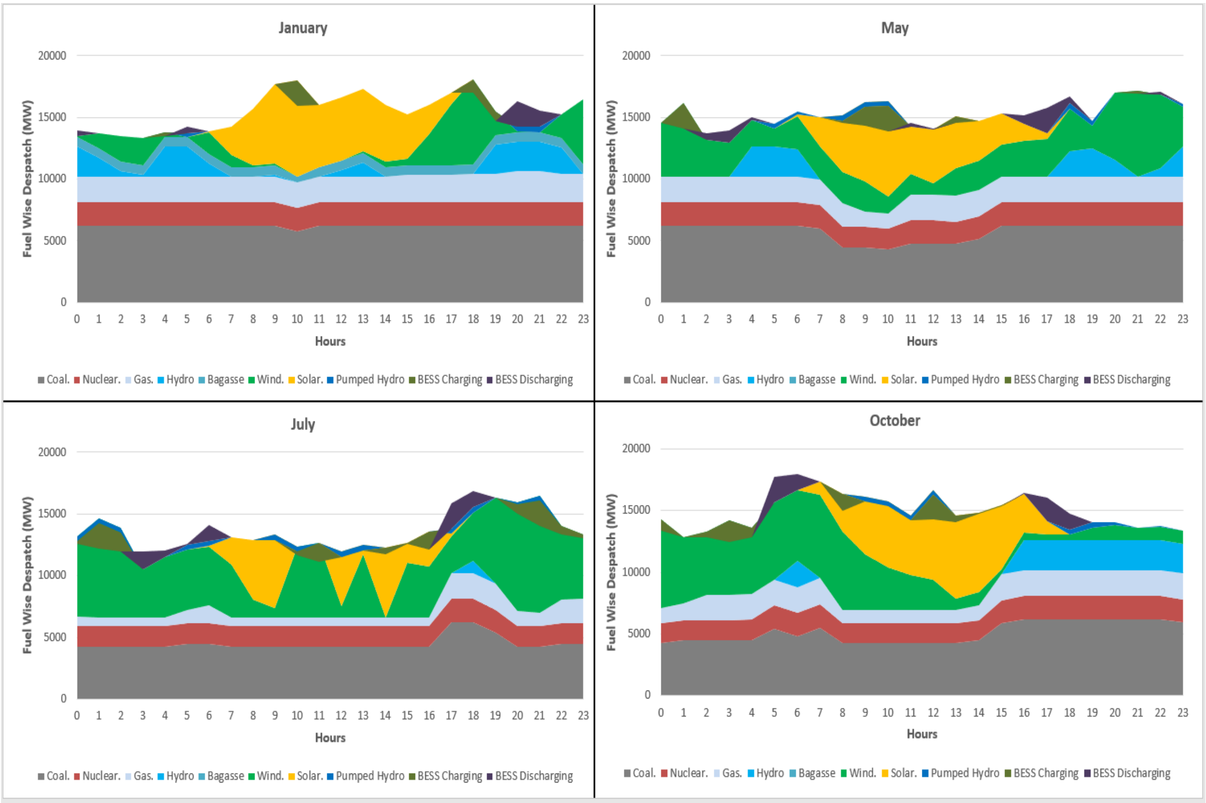


Figure 17: Seasonal Dispatch Profile - High RE Scenario – 2025

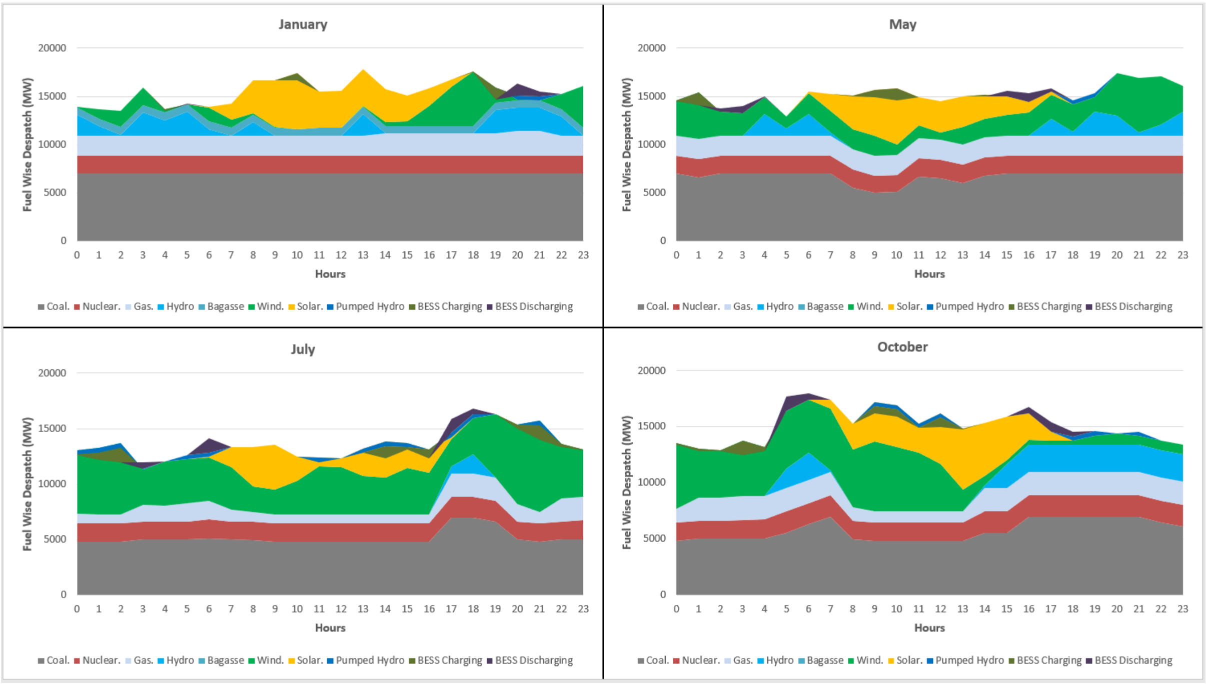


Figure 18: Seasonal Dispatch Profile - Low RE Scenario - 2025

4.1.4 Overall BESS Penetration

The model recommends 1 and 2 hours of BESS in both HRS and LRS for 2025, as shown in ***Figure 19***. The amount of storage for high RE case is more in the 2-hour duration than in Low RE Scenario. The system does not accommodate any further pumped hydro addition in the generation mix, beyond 400 MW of PHS which is already present in the state grid.

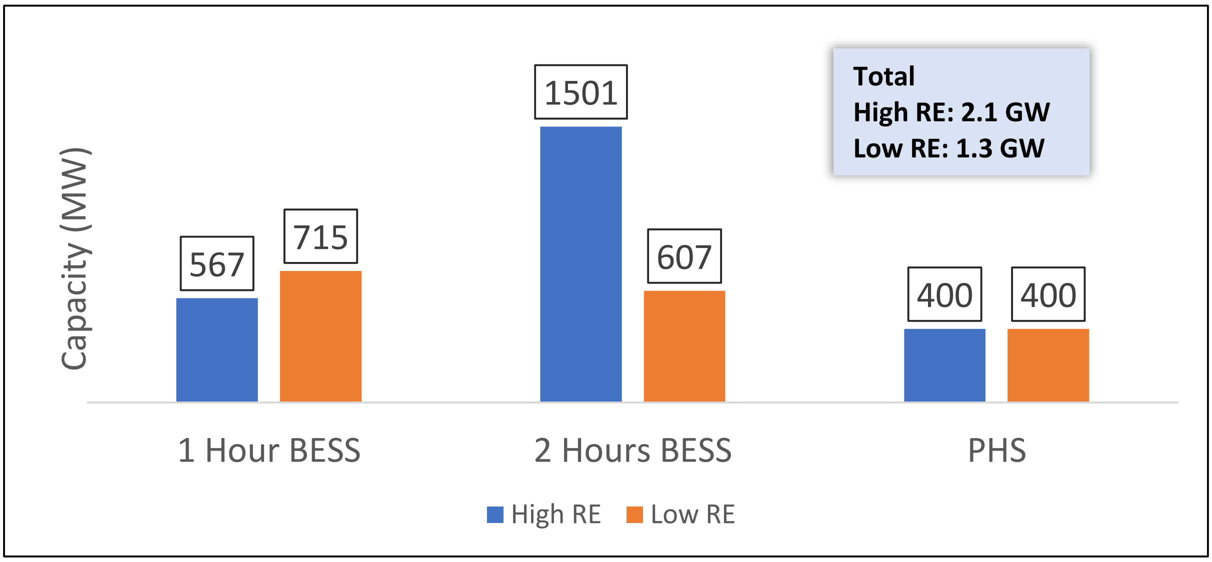


Figure 19: BESS Penetration - 2025

4.1.5. Overall System Level Cost Benefits

In both high and Low RE Scenarios, it is observed that there is reduction in system level cost with installation of energy storage in the TN grid. Benefits are more in the form of reduction of fixed and variable costs due to less use of coal and minimal expansion of coal plants in the state. As seen in ***Figure 20***, it is observed that there is benefit of INR 1,800 crore in the High RE Scenario and INR 900 crore in the Low RE Scenario when storage is integrated in the grid.

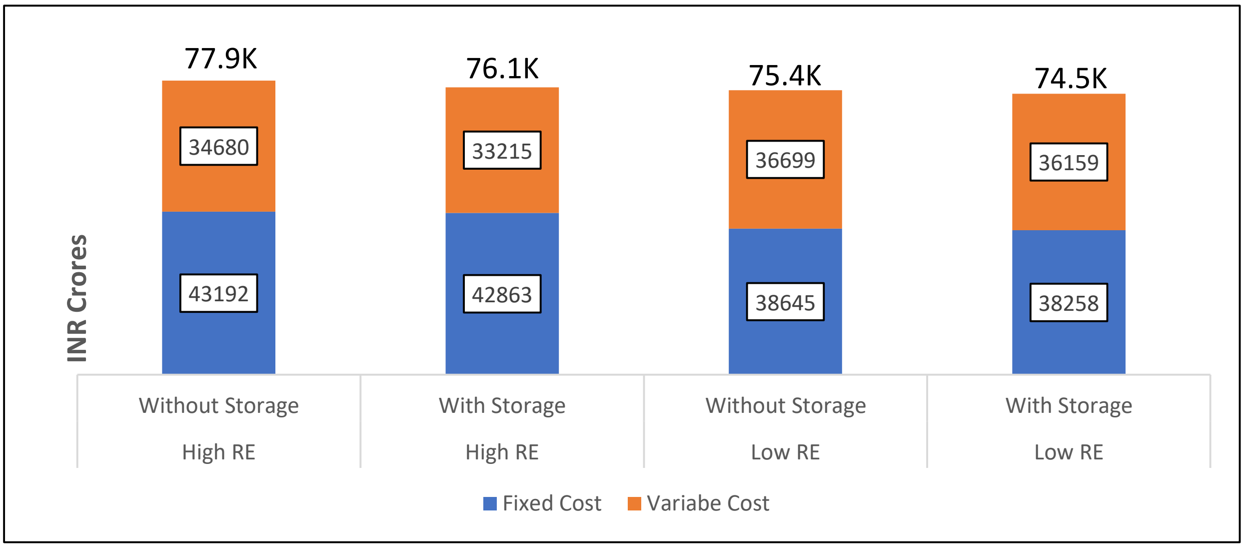


Figure 20: System Level Cost - 2025

4.2 Year 2030

In 2030, model inputs are taken from the outputs of 2025 model scenario run.

4.2.1 High RE Scenario (HRS)

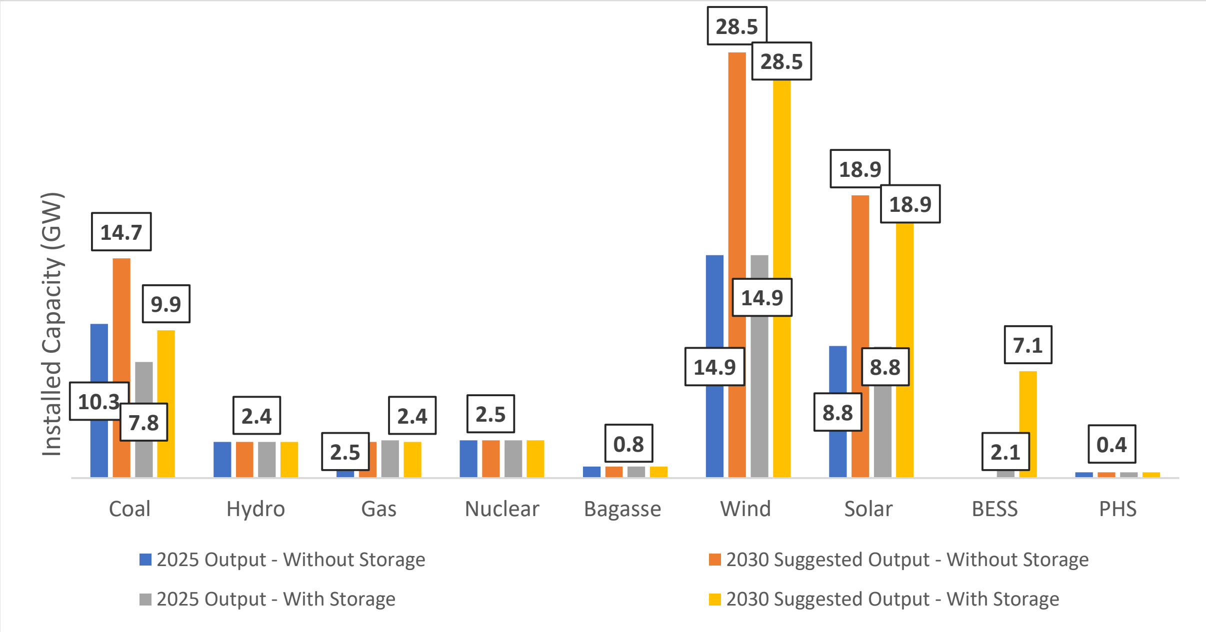


Figure 21: Installed Capacity - 2030 - High RE

Capacity Addition

In the 2025 high RE case model run, capacity of coal was observed to be 10.3 GW and 7.8 GW in 'without storage' and 'with storage' cases, respectively. In 2030, the model suggests addition of 4.4 GW to the existing capacity of 10.3 GW in 'without storage' case. This addition is against a planned addition of 8.9 GW between 2025 and 2030 for the state as per the State Energy Policy Document. With inclusion of storage, the addition of new coal units is limited to 2.1 GW to the existing capacity of 7.8 GW. The model suggests retirement of the oldest gas unit in the state (120 MW capacity). Total renewable capacity stands at 28.5 GW for wind and 18.9 GW for solar in 2030.

Projection Years	Wind Capacity (GW)	Solar Capacity (GW)	Peak Demand (GW)	Annual power demand (MU)	% Annual Demand met by RE
2020 (base line)	9.3	3.9	17.3	110,815	23%
2025	14.9	8.8	20.9	129,976	33%
2030	28.5	18.9	26.4	171,149	42%

Table 10: 2030 High RE Scenario

Capacity addition of all other fuel sources are taken as per the State Energy Policy document with hydro, nuclear and bagasse at 2.4 GW, 2.5 GW and 0.8 GW, respectively.

Output	With Storage Case			Without Storage Case		
	GW	% Energy	PLF (%)	GW	% Energy	PLF (%)
Coal	9.9	32	62	14.7	48	60
Wind	28.5	30	20	28.5	24	15
Solar	18.9	12	13	18.9	10	8

Table 11: 2030 High RE Generation Mix

Storage Penetration

In high RE case, the model suggests addition of 5 GW of BESS in addition to 2.1 GW of BESS already installed in the state grid in 2025, taking the total cumulative BESS installed capacity to 7.1 GW (refer ***section 4.2.5. Overall BESS Penetration***). The duration of storage in 2030 increases to 4 and 6 hours (3.4 GW – 4 Hours, 1.7 GW – 6 Hours). The model retains 400 MW of pumped hydro capacity already present in the grid, with no further expansion.

Renewable Spillage

It is observed from the model that there is significant increase in the percentage of spillage observed for renewables. The model projects higher spillage of solar (66% from 45% in 2025 levels, the same reduces to 45% when storage is introduced). Wind spillage is projected to increase significantly to 48%. The same is projected to reduce to 30% with penetration of storage in grid. The spillage here gets more pronounced throughout the year than just being limited to the high RE months showing that the state may be running at an overcapacity of renewables than what can be absorbed in a sustainable way. The model does not account for system exports; however, some part of this spillage can be absorbed if the system exports are allowed in the future.

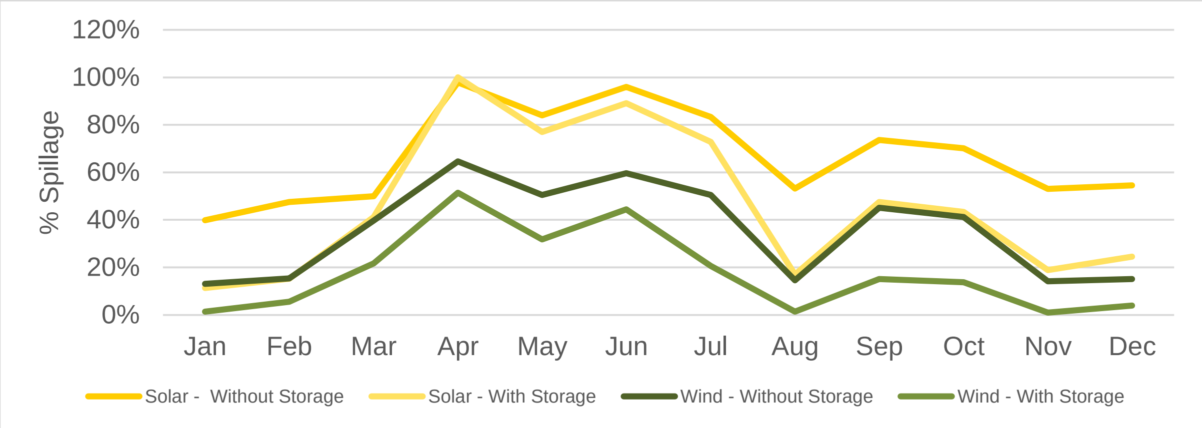


Figure 22: RE Spillage Trend - High RE - 2030

Resource Utilization

In terms of utilization of resources, coal utilization improves from 60% to 62% with storage inclusion while coal's generation share reduces from 48% to 32%. This is partly explained by the increasing generation share of renewables (42% generation share in 'with storage' case, while 31% in 'without storage' scenario). The generation share of renewables increases by 11% due to inclusion of storage which helps in absorbing excess RE generation. RE utilization shows improvement with inclusion of storage (for example, PLF for wind improves to 20% with storage from 15%). Further, improvement in PLF of gas is also observed in this scenario (45% to 52%). Imports in 2030 drops to 1.5% as opposed to 5.6% of the generation mix in 2025.

System Level Costs – Benefits

This scenario sees a saving on the system level cost of INR 5,700 crore. Benefits of cost are observed to be more due to the reduction in fixed cost here along with benefits visible in savings from variable costs. The total system level cost with storage in the high RE scenario with inclusion of 5 GW of storage is INR 119,885 crore against INR 125,653 crore with presence of more coal in the grid. The system also projects a saving of 4 million tons of CO_2 with inclusion of storage in the grid.

4.2.2 Low RE Scenario (LRS)

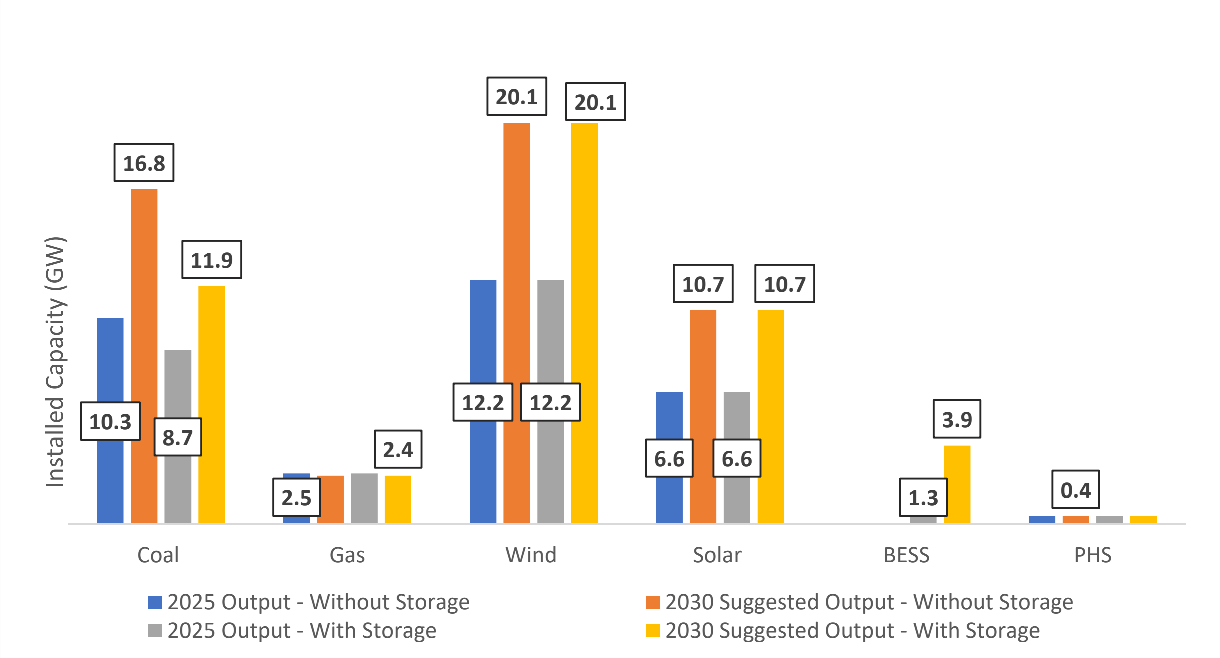


Figure 23: Installed Capacity - Low RE - 2030

Capacity Addition

In the 2025 low RE case, the capacity of coal stood at 10.3 GW and 8.7 GW in 'without' and 'with storage' cases, respectively. The model suggests addition of 6.5 GW to the existing capacity of 10.3 GW in 2030 in 'without storage' case. This addition is against a planned addition of 8.9 GW between 2025 and 2030 for the state as per the State Energy Policy Document.

Projection Years	Wind Capacity (GW)	Solar Capacity (GW)	Peak Demand (GW)	Annual power demand (MU)	% Annual Demand met by RE
2020 (base line)	9.3	3.9	17.3	110,815	23%
2025	12.2	6.6	20.9	129,976	28%
2030	20.1	10.7	26.4	171,149	33%

Table 12: 2030 Low RE Scenario

With inclusion of storage, the addition of new coal units is limited to 3.2 GW. The model suggests retirement of oldest gas unit in the state of 120 MW capacity since it is the most expensive power producer. Total renewable capacity in this scenario is 20.1 GW for wind and 10.7 GW for solar. The capacity addition of all other fuel sources is taken as per state plan. The cumulative capacity of hydro, nuclear and bagasse therefore are kept at 2.4 GW, 2.5 GW and 0.8 GW respectively.

Output	With Storage Case			Without Storage Case		
	GW	% Energy	PLF (%)	GW	% Energy	PLF (%)
Coal	11.9	40	65	16.8	53	61
Wind	20.1	24	24	20.1	19	18
Solar	10.7	9	17	10.7	8	14

Table 13: 2030 Low RE Generation Mix

Storage Penetration

The model suggests further addition of 2.6 GW of BESS in addition to 1.3 GW of BESS already installed in 2025, taking the total cumulative BESS installed capacity to 3.9 GW. The duration of storage in 2030 spans around 1 to 4 hours (26 MW – 1Hr, 960 MW – 2 Hr, 1.6 GW – 4 Hr), detailed further in ***section 4.2.5***. The model retains the 400 MW of pumped hydro capacity already present in the grid, with no further expansion.

Renewable Spillage

It is observed from the model that there is a significant increase in the percentage of spillage observed for renewables in 2030 low RE scenario when compared to 2025 levels. Spillage for solar increases to 39% from 18% in 2025 levels, which reduces to 26% when storage is introduced. For wind, there is significant spill over as shown by the model in order of 38%, which reduces to 18% with penetration of storage in the grid. The spillage here gets more pronounced throughout the year than just being limited to the high RE months showing that the state may be running at an overcapacity of renewables than what can be absorbed in a sustainable way. The model does not account for system exports, however, some part of this spillage may be absorbed if the system exports are allowed in the future.

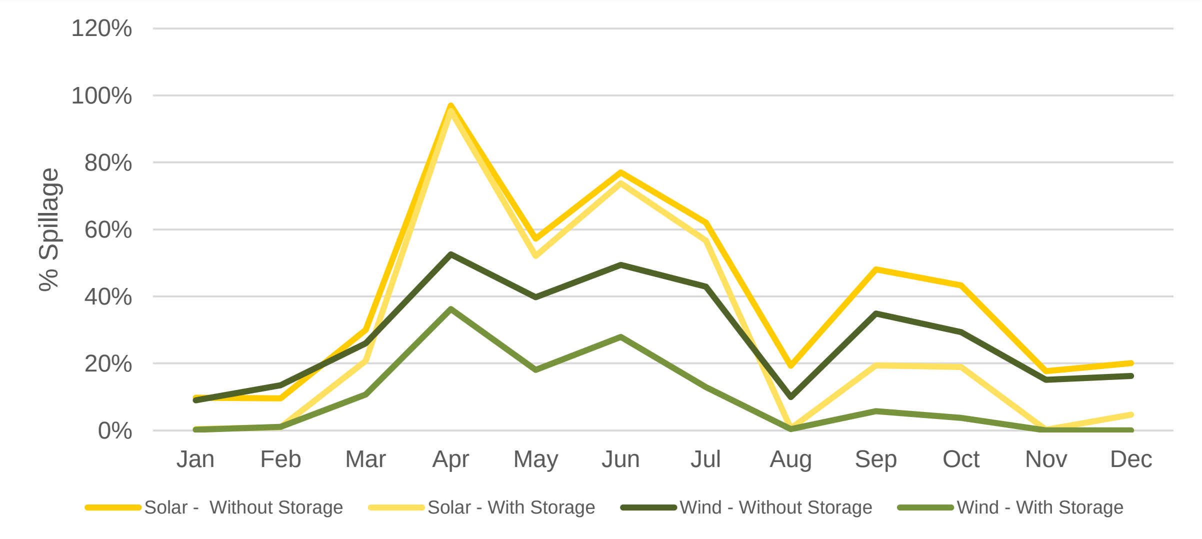


Figure 24: RE Spillage Trend - Low RE - 2030

Resource Utilization

Utilization of coal remains at 60% while coal's generation share reduces from 53% to 40% in this scenario. This is partly explained by the increasing generation share of renewables (34% generation share in 'with storage' case, whereas 27% in 'without storage' scenario). The generation share of renewables increases by 7% due to inclusion of storage which helps in absorbing excess RE generation. PLF of wind without storage is 18%, which improves to 24% with storage. Due to more utilization as a flexible resource, improvement in PLF of gas is observed - 52% to 66%. Imports in 2030 drops to 2.3% from around 3% of the generation mix in 2025.

System Level Costs - Benefits

This scenario sees a saving on the system level cost of INR 6,800 crore. Benefits of cost are observed to be more due to the reduction in fixed cost. The total system level cost with storage in the low RE scenario with inclusion of 2.6 GW of storage is INR 112,264 crore against INR 119,066 crore. The system also projects a saving of 3 million tons of CO_2 with inclusion of storage in the grid.

4.2.3. Minimum RE Scenario (MRS)

In both the High and Low RE Scenarios it was observed that there is an increasing amount of spillage in the state. The spillage increases to 66% in 2030 for High RE case, 45% in low RE due to solar alone and 48% in 2030 High RE Scenario due to wind. Thus, a scenario was created to understand what will be the impact on the system level cost if there is better utilization of RE capacity present in the grid, thereby reducing spillage cases. The inputs from 2025 Low RE Scenario were fed as inputs to this model run in 2030.

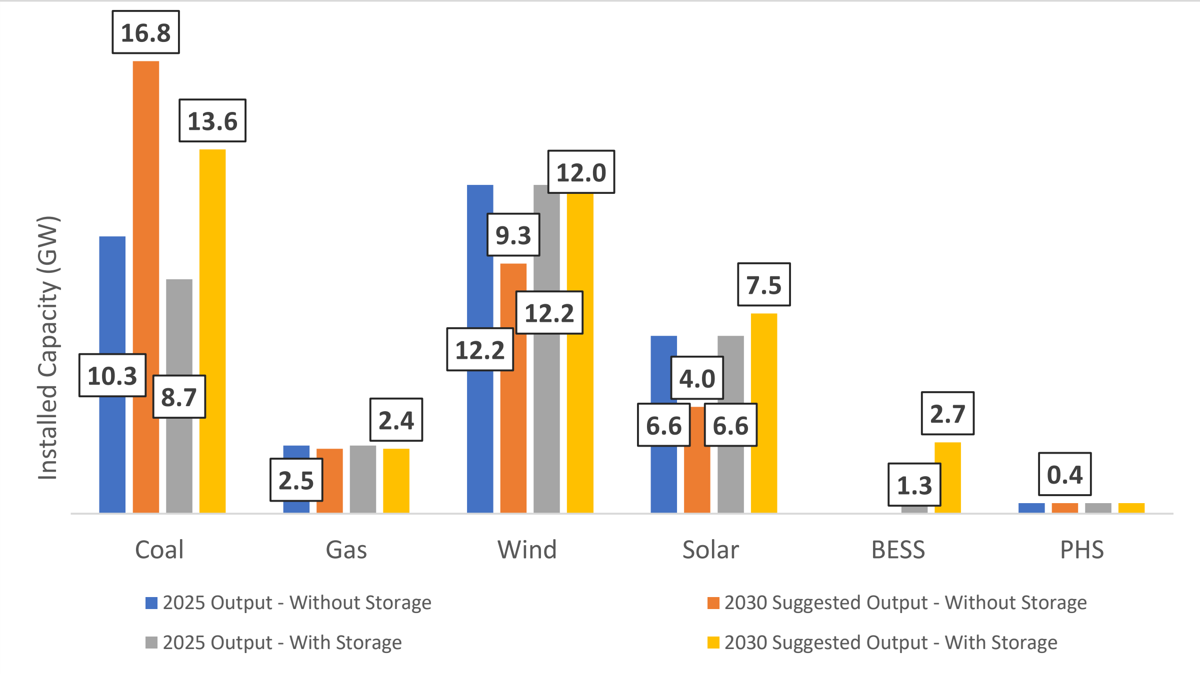


Figure 25: Installed Capacity – Minimum RE Scenario - 2030

Capacity Addition

It is observed that the model projects a larger addition of coal to the grid. The capacity of coal was 10.3 GW and 8.7 GW in 'without' and 'with storage' cases, respectively. The model suggests addition of 6.5 GW (like low RE case) to the existing capacity of 10.3 GW in 'without storage' case. This addition is less than the total allocated capacity of 8.9 GW for the state as per the State Energy Policy Document.

Years	Wind Capacity (GW)	Solar Capacity (GW)	Peak Demand (GW)	Annual power demand (MU)	% Annual Demand met by RE
2020 (base line)	9.3	3.9	17.3	110,815	23%
2025	12.2	6.6	20.9	129,976	28%
2030	12.0	7.5	26.4	171,149	25%

Table 14: 2030 Minimum RE Scenario

With inclusion of storage, the addition of new coal is limited to 4.8 GW to the existing capacity of 8.7 GW already present in the grid, taking the total cumulative installed capacity of coal to 16.8 GW and 13.6 GW in 'without' and 'with storage' cases, respectively. The model suggests retirement of 120 MW capacity of gas in 2030 (like other scenarios).

For renewables, the model projects that the state without storage penetration may not require any further addition of renewables. The model suggests the optimal capacity of wind in the state by 2030 to be 9.3 GW and for solar to be 4 GW. It is interesting to note that both values are lower than the suggested capacities of renewables in 2025 and almost mimics current renewable installed capacity in the state in 'without storage' case. With inclusion of storage (1.3 GW), the model projects no further installation of wind and projects the capacity as it was in 2025, i.e., 12 GW. For solar, a small addition is seen from 2025 level: 7.5 GW in 2030 against 6.6 GW in 2025. The model retains the 400 MW of pumped hydro already present in the system.

Output	With Storage Case			Without Storage Case		
	GW	% Energy	PLF	GW	% Energy	PLF
Coal	13.6	47	67	16.8	57	65
Wind	12.0	17	27	9.3	13	27
Solar	7.5	8	20	4.0	4	19

Table 15: 2030 Generation Mix – Minimum RE Scenario

Storage Penetration

The model suggests further addition of 1.3 GW of BESS in addition to the 1.3 GW of BESS already installed in 2025, taking the total capacity of BESS to 2.6 GW. The duration of storage in this case are in the range of 1- and 2-hour durations (combination of 8 MW – 1 Hour and 1.3 GW – 2 Hour). The model retains the 400 MW of pumped hydro capacity present in the grid, with no further expansion.

Renewable Spillage

It is observed that there is significant reduction in RE spillage in this scenario. The model projects solar spillage of 16%, which further reduces to 11% with storage, whereas spillage for wind is limited to only 7%, a marked improvement as compared to all the above scenarios.

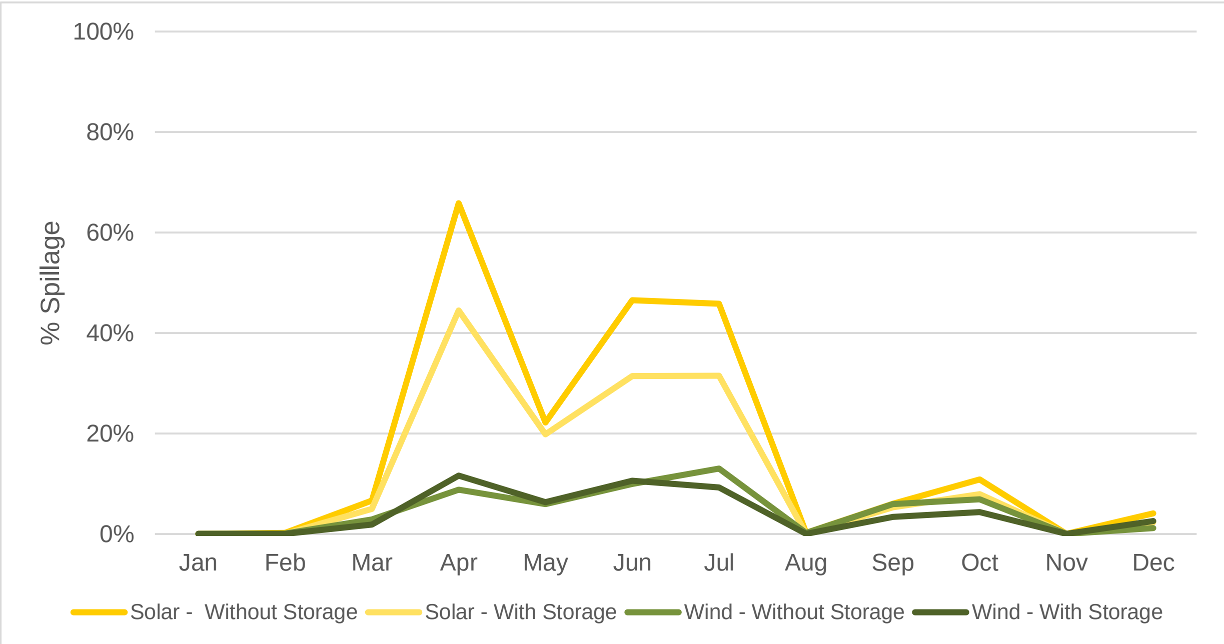


Figure 26: RE Spillage Trend – Min RE Scenario - 2030

Resource Utilization

Utilization of coal increases to 67% while coal's generation share increases to 47% as compared to the other scenarios where the generation share of coal was 30-40%. This is because of greater coal addition suggested in the grid in this scenario. The generation share of renewables show improvement with inclusion of storage, an 8% increase. RE utilization shows marked improvements in this scenario-wind PLF increases to 28% and solar to 20%. Improvement of gas utilization is also noticed due to a more prominent role of gas as a flexible resource in this scenario (utilization – 78%). Flexible operation of coal is seen to increase as well. Imports also increases to 3% of the total generation share.

System Level Costs - Benefits

In terms of system level costs, there is an increase observed in fixed cost due to addition of coal capacity but there is a drop in variable cost. Overall benefits in this scenario with storage is INR 500 crore. The system level cost improves from INR 110,524 crore to INR 110,170 crore. In terms of emission there is a savings of 4 million tons of CO_2, but the amount of emission in this case is higher than earlier cases, mainly due to more coal being utilized in the grid.

4.2.4. Overall Seasonal Dispatch Profiles

The dispatch profiles for 2030 were studied for the months of January, May, July, and October as sample months. Overall, the applications that storage served the grid for 2025 remains the same but with much greater capacity and longer durations of BESS. It was observed that coal in the grid was restricted to technical minimum limits almost throughout the year.

There are significant short-term variations observed in the month of January where BESS helps in smoothening out the RE load curves. When compared to January 2025, it is observed that the duration and magnitude of storage is much more. The evening peak management duration in this case is extended to 4 hours (6 pm to 10 pm on an average). Whereas during the day, the amount of time indicated for charging also shows an increase. This is because the grid now has more renewables penetration than in the 2025 scenario (42% in terms of generation share in 2030 High RE Scenario in 'with storage' case). More applications that storage serves in the months of high RE availability like May and July can be explored. In the month of May, storage discharge is projected to remain for the entire non-solar hours, i.e., the duration of storage here will be longer. During periods when wind availability is particularly high, it is observed that solar is mostly used to charge the batteries during the daytime and the same is utilized for providing energy to the grid in the non-solar hours. Wind remains as the main VRE resource utilized for balancing load. In both these months, coal, nuclear, and gas resources are mostly restricted to catering the base load throughout the day. As explained in the 2025 scenario, the application that storage serves remains the same in the Low RE Scenario too but with lower duration and capacity requirements. In the Minimum RE scenario, the applications and pattern of usage of storage remains similar to the Low RE Scenario but coal is observed to play a more flexible role apart from catering to base load. RE spillage is observed to be quite low in this scenario as the RE addition to the grid is also limited (25% penetration). Nevertheless, storage is required for capturing potential spillage. All the three scenario seasonal dispatch profiles are shown in ***Figure 27, Figure 28*** and ***Figure 29***.

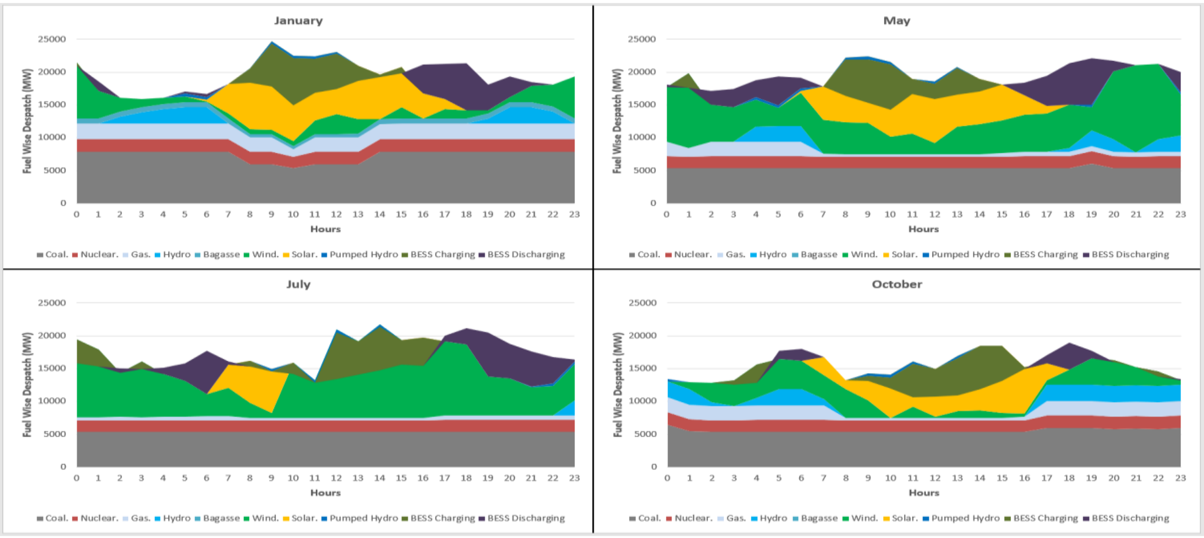


Figure 27: Seasonal Dispatch Profile - High RE Scenario - 2030

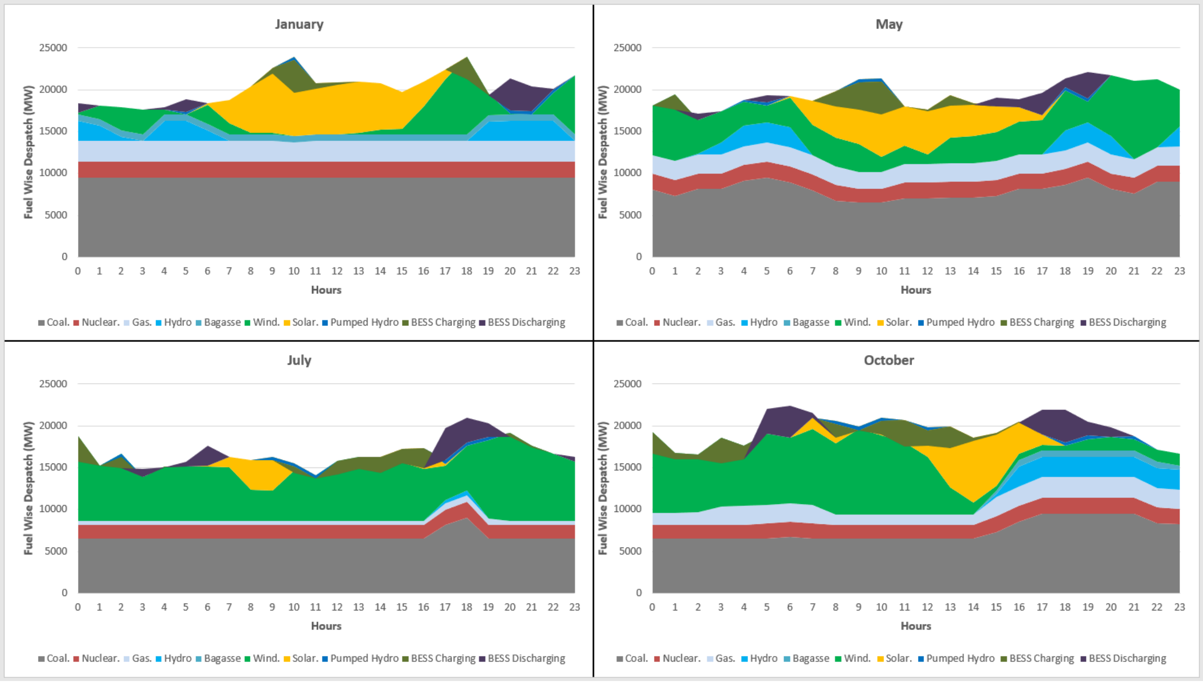


Figure 28: Seasonal Dispatch Profile - Low RE Scenario - 2030

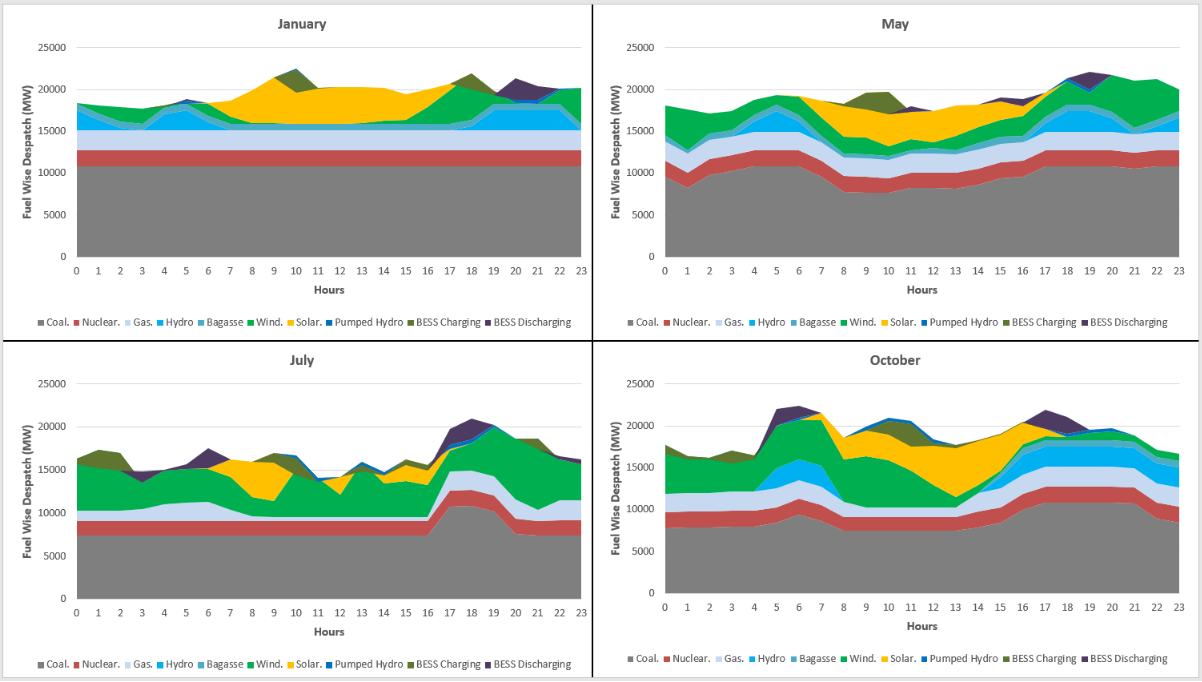


Figure 29: Seasonal Dispatch Profile - Min RE Scenario - 2030

4.2.5. Overall BESS Penetration

BESS penetration in 2030 becomes much more prominent in the grid in all the scenarios. The model projects a combination of 4 hours and 6 hours storage in the High RE scenario; 1 to 4 hours for the Low RE scenario and 1 to 2 hours for Minimum RE scenario to balance the grid.

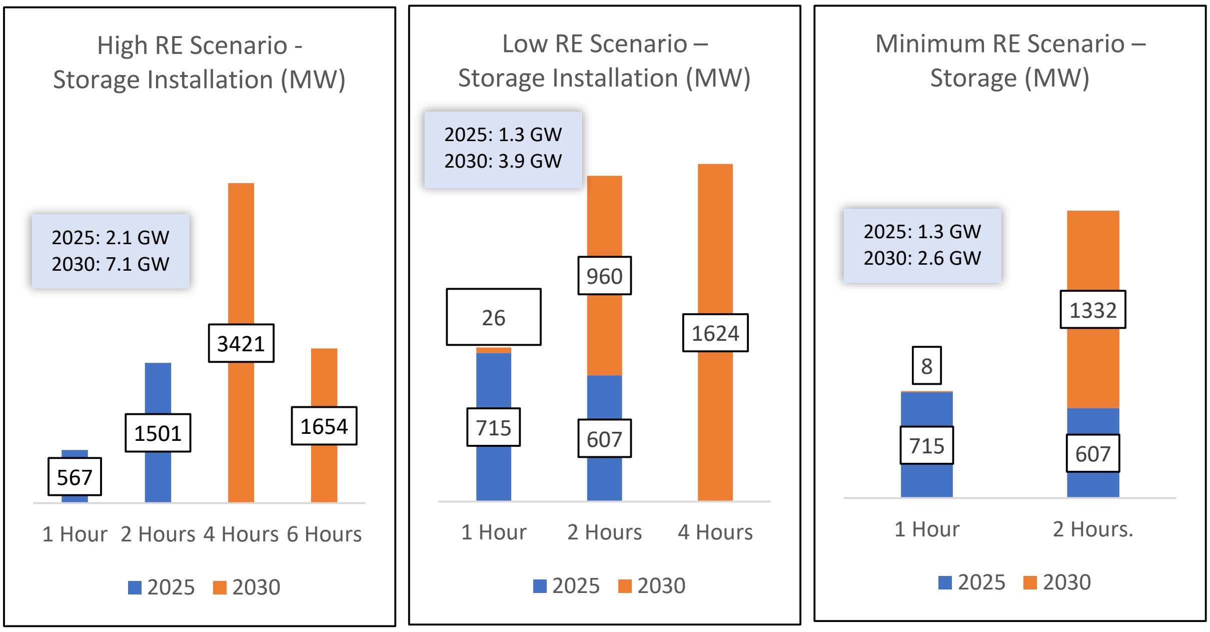


Figure 30: BESS Penetration – 2030

4.2.6 Overall System Level Cost

The model projects savings of total system costs for cases 'with storage' when compared to cases 'without storage'. This is explained by less new coal addition in the system especially in 'with storage' case. This scenario run showed that in spite of minimum addition of RE capacity in 2030 grid as compared to the present 2020 levels, there is still a need for BESS to balance the grid, minimize RE spillage and optimally utilize existing coal resources thereby keeping system level costs very low. However, it was observed that the emission levels still remain high as compared to low and high RE scenarios.

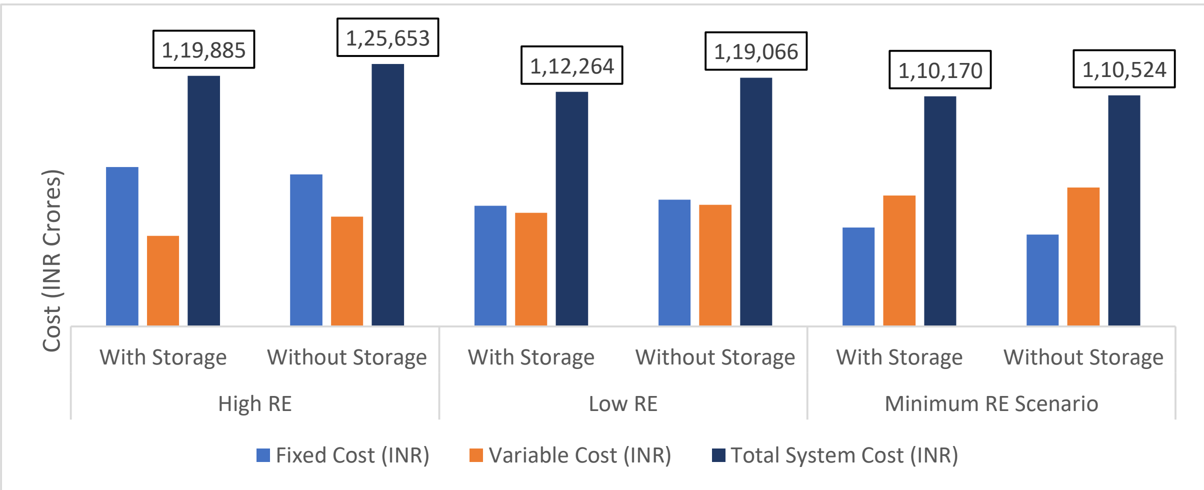


Figure 31: System Level Cost -2030

4.3 Carbon Dioxide Emission

The model output projects an increasing amount of savings in CO_2 emissions over years with penetration of storage in the generation mix. The below table shares the amount of benefit in various scenarios which is delivered through penetration of storage in ***Figure 32.***

Year	Scenario	%age CO2 emission Benefit
2025	High RE	23%
2025	Low RE	17%
2030	High RE	16%
2030	Low RE	11%
2030	Minimum RE	6%

Table 16: CO_2 Emission Trend

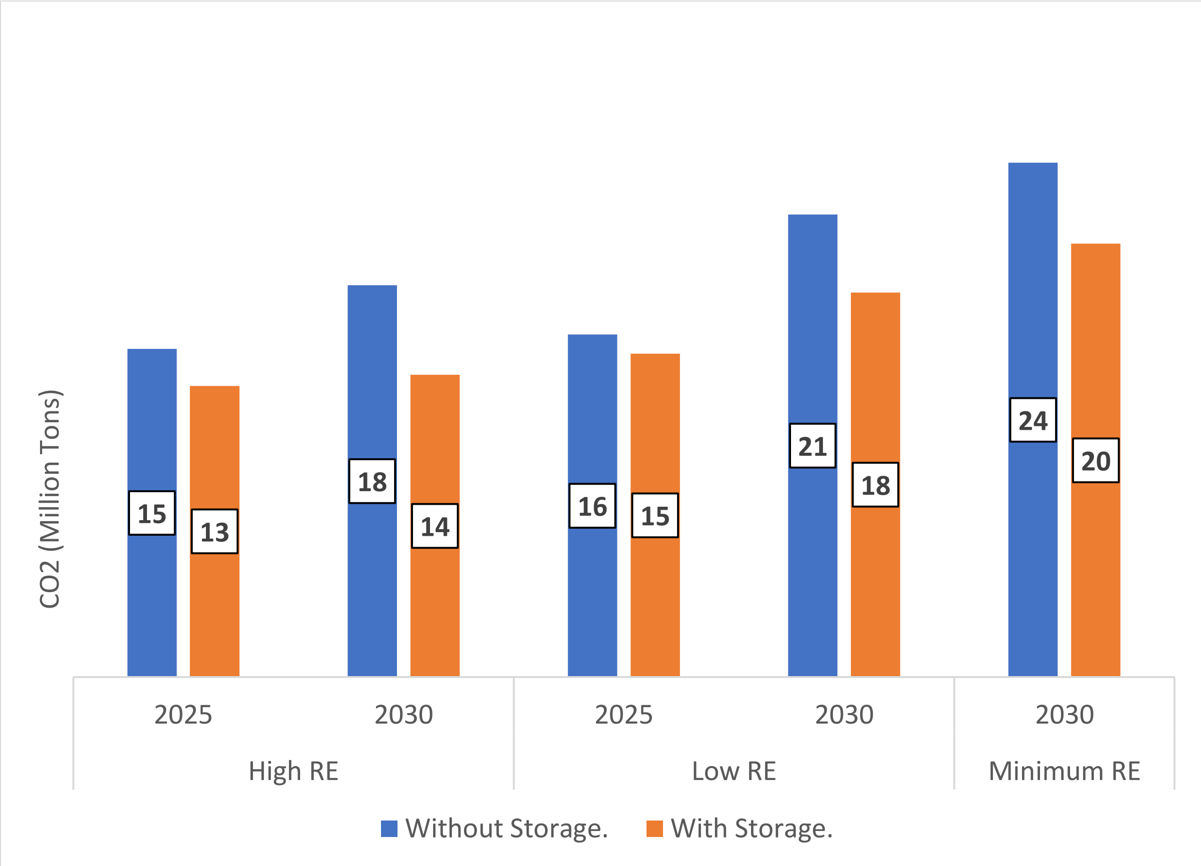


Figure 32: CO_2 Emission Trend

5. Project Analysis: Techno-Commercial Viability

5.1 Scope and Objective of the Analysis

The objective of CoMETS analysis is to evaluate economics of a BESS project in Tamil Nadu. The analysis in this study captures the local benefits of a BESS at a substation or feeder level and evaluates its economic viability. All these benefits are stacked to evaluate the savings and revenue streams. Prioritizing one revenue stream affects the other, hence, optimizer evaluates the best possible case. The steps were to (a) calculate savings and benefits over the years, (b) capture costs including Capital Expenditure (CAPEX) and Operating Expenditure (OPEX) and (c) finally arrive at the financial parameter such as NPV, IRR, income statement and cash flows.

5.2 Assumptions and Methodology

1. **Dispatch of storage**: It is assumed that the storage operation will be similar to dispatch obtained from system analysis. This makes sure that the benefits to system are rightly captured. Production cost analysis provides the size, benefits, and dispatch of the total BESS in the system. The storage project is assumed to be a fraction of the size of the storage potential obtained at system level. Thus, it is assumed that the benefits too would be a fraction of the total benefits at the system level.
2. **Annualization of data**: Since the dispatch data was available for certain days/weeks in a year, the benefits and savings obtained at project level needs to be scaled appropriately for annualization of revenues.
3. **Storage Replacement**: Considered replacement schedules of storage based on the cycling obtained from the dispatch.
4. **T&D deferral**: There is a local node assumed at the point of installation of storage project. The project analysis calculates the load reduction during peak hours due to storage, which further helps in calculating T&D deferral benefits. It is assumed that the utility or any appropriate stakeholder will raise debt for the upgradation of the line capacity. The deferred payments due to deferred upgrades are the real benefits.

   Project ownership: Assumptions are made regarding the ownership of the storage. Whether IPP, utility or state owned. This has implication on benefits that are monetizable to the project. The benefits which are not monetizable are benefits nonetheless for the system. These benefits can be passed on to the project through some incentive program.

Storage

Power Rating	**10**	MW
Duration	**1hr, 2hr, 4hr, 6hr**	
Charging efficiency	**95%**	
Discharging efficiency	**95%**	
PCS Capex	**14,000**	INR/kW
Storage Capex	**21000**	INR/kWh
Opex	**675**	INR/kWh
Storage Life	**10**	years

Project

Project Life	10	years
Depreciation	5	years
Discount Rate	10%	
Tax Rate	35%	

Policy

Capacity payments	**900**	INR/kW/Month
*these values are subjected to change according to analysis		
Grants		
Percent of captial	**30%**	

T&D upgrade parametes

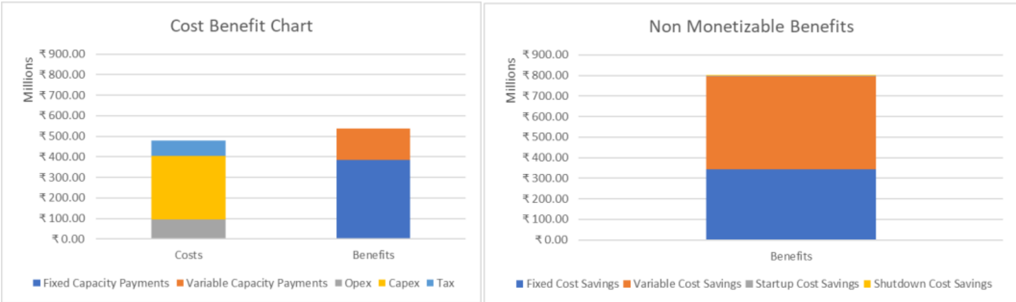
Upgrade costs	Changes project to project	
Line capacity		MW
Growth Rate	2%	
Load profile of facility		
Interest rate	5%	
Tenure	20	years

Figure 33: Key Assumptions

5.3 Economics of Renewable + Storage Projects

The project level analysis indicates that all the benefits can be monetized if the project is owned by the utility. For IPPs, it is assumed that they will operate their BESS according to dispatch required by the system. A system will need to be in place to monitor the compliance of individual project within the system.

Following is the example of a 10MW/20MWh storage project owned by IPP:



IPP Owned

Benefits

Fixed Capacity Payments	₹	38,58,06,624
Variable Capacity Payment:	₹	15,31,80,119
Total	**₹**	**53,89,86,743**

Costs

Opex	₹	9,53,12,981
Capex	₹	30,98,10,000
Tax	₹	7,44,02,119
Total	**₹**	**47,95,25,100**

NPV	**₹ 5,94,61,641**
IRR	**16%**

Utillity Owned

Benefits

Fixed Cost Savings	₹	34,28,03,914
Variable Cost Savings	₹	45,11,71,667
Startup Cost Savings	₹	36,71,534
Shutdown Cost Savings	₹	12,62,763
Total	**₹**	**79,89,09,878**

Costs

Opex	₹	9,53,12,981
Capex	₹	30,98,10,000
Tax	₹	16,40,49,259
Total	**₹**	**56,91,72,240**

NPV	**₹ 22,97,37,639**
IRR	**25%**

Figure 34: Cost Benefit Analysis

From the above data, it can be observed that operating the asset purely as a utility-owned project yields 25% IRR. All those benefits become non-monetizable when operated as an IPP. To make this lucrative for IPPs, there needs to be a policy mechanism in place to channel the monetary benefit from utility to IPP. In this case, those are channeled in the form of fixed and variable capacity payments. In this scenario, the asset receives some fixed monthly payments INR/kW/month (assumed as INR 450/kW/month). The asset is operated as per the dispatch scheduled by the utility. The other part is the variable payment. The energy discharged by the asset gets paid by a defined INR/kWh value (assumed as INR 10/kWh). A contract can be signed between the utility and IPP to set these prices. In the above case, the prices are set such that the IPP gets paid fixed and variable payments and the IRR for the project works out to be 16%. Thus, the total NPV benefit to the system is INR 79.89 crore due to the asset, of which INR 53.89 crore goes to IPP and INR 26 crore goes to utility, which is a win-win situation for both utility as well as IPP.

6. Conclusion & Recommendations

The study highlights key findings of the analysis and opportunities for storage adoption that the state could leverage:

- With increase in the percentage of renewables in the grid, the need for storage system to store excess energy increases
- There is significant unutilized thermal capacity in both high and low renewable penetration scenarios for the year 2025 and 2030 due to must-run status of RE and high generation costs of thermal plants. Some of these thermal plants are below their PPA life of 25 years. The state could either explore ways to better utilize these resources for flexibility purposes or can consider them for retirement based on the cost of supply and emissions from these plants, especially for plants which are closer to 25 years of life. A list of all coal plants in the state which are nearing their PPA life is detailed in Annexure B: Plant Retirement List - Coal
- Seeing the projection and targets laid for the state, it would be thus prudent to have a long-term plan so that the expansion of both thermal and RE is done in an integrated manner, otherwise there could be a lot of spillage, especially if storage is not integrated in the grid
- Tamil Nadu state would need to install 1.3 GW/1.9 GWh of BESS by 2025 to support RE expansion under Low RE scenario, whereas under High RE scenario, the state would need to add 2.1 GW/3.6 GWh. In High RE scenario, requirement for 2 hours storage increases to 1500 MW as compared to 600 MW required under Low RE scenario.
- By 2030, the state would require 2.7 GW/5 GWh of BESS for minimum RE scenario to economically balance the grid. However, the requirement of BESS would grow to 3.9 GW/10 GWh in Low RE scenario and 7.2 GW/27 GWh in High RE scenario. Higher the renewable penetration, more would be the requirement for long duration storage (6 hours duration).
- The option of making coal fleet more flexible by lowering of technical minimum set point from 55% as prescribed by CEA to 40% was also checked as a scenario. It was observed that there was a reduction in system level cost when the coal plants were operating at 40% as compared to 55% due to greater utilization of coal. The state utility could plan for undertaking pilot cases to test flexibility of selected thermal plants.

Recommendations to TANGEDCO:

- Updating the generation and transmission planning procedures used by the utilities and the regulators
    a. Traditional ways of planning the generation based only on the peak demand may not suffice in future due to increasing renewable generation capacity which has temporal and spatial variation in the generation pattern. Also, given the possible uptake of electric vehicles and demand response in future years, the demand pattern may change. Hence, the generation planning and transmission planning may become a complex exercise
    b. Storage has significant potential to lower the future system costs. However, the charging and discharging of the storage is dependent on the availability, maintenance patterns, and costs of other types of generation. To model this complex dependency of different generation resources for estimating the storage benefits, the utilities can use production cost models. These models will also help the utility to minimize the system costs by improving its overall generation utilisation in different medium and long- term scenarios. Insights from the modelling exercise can be used to modify operational patterns of dispatchable generating resources

- Utilities can determine setting medium-term and the long-term targets for deployment of storage in the system based on the results of modelling scenarios. This will help the utility to determine yearly capacity addition of the storage along with capacity additions of the renewable generation resources
- The storage can be owned by the utility or by an IPP. If the storage is owned by the utility, utility will incur fixed cost per kWh of the asset every year based on the financing structure. Also, the utility can realize savings in variable cost, start-up cost, shutdown cost of generation fully. However, when the storage is owned by an IPP, the utility can pay fixed cost per kW and variable cost per kWh to the IPP. In this case, the utility can give dispatch instructions to storage and adjust the variable payment depending on how accurately the storage asset follows the dispatch. In both cases, the utility would be able to reap maximum benefits if the storage follows the dispatch pattern accurately
- In addition to the energy arbitrage, the storage can provide multiple ancillary services like frequency regulation, spinning reserves, black start etc. The utility can realize more benefits if the storage is used for supplying these ancillary services.

Recommendations to the Regulators and Policymakers:

- It would be beneficial to conduct a study to identify applications of storage which are suitable and most beneficial to the grid, subject to our existing regulatory structure and procedures for market settlement. A resource-neutral market can be created for each applications of storage based on which the system operators can procure resources for meeting its requirement.
- Depending on the market developed for each application of ancillary services, a commercial settlement procedure for storage can be added in the tariff regulations of the respective SERC or the CERC. In most ISOs in other countries, storage gets paid capacity revenue for participating in meeting the ancillary service requirements of ISOs. Depending on the actual delivered amount of energy while providing the ancillary services, additional payment is given to/from the storage resource.
- The existing regulations regarding operating, metering, accounting, and settlement procedures will need to be amended to allow the storage to provide these multiple services simultaneously.
- The key to ensure increased deployment of storage in the future will be to create targets for storage and a corresponding transparent market structure for participation of storage. This can indicate a consistent trend of cash flows from different applications to the energy storage investors. Going forward, ensuring resource-neutral markets will decrease uncertainty associated with estimating cash flows of energy storage projects.

7. Annexures:

A. Plant Retirement List - Coal

Plant Details					High RE		Low RE		Retirement Plan as per NEP 2018	High RE (with unutilized coal) - 2030		Low RE (with unutilized coal) - 2030	
Sr No	Plant Name	Rated Power (MW)	Age as on 2025	Age as on 2030	Without Storage	With Storage	Without Storage	With Storage		Without Storage	With Storage	Without Storage	With Storage
1	NEYVELI LIG. CORP. LTD.	1066	13	18		y		y	No				
2	NEYVELI LIG. CORP. LTD.		12	17		y		y	No				
3	NEYVELI LIG. CORP. LTD.		10	15		y		y	No				
4	NTECL	210	38	43	y	y	y	y	Yes				
5	NEYVELI LIG. CORP. LTD.	210	38	43	y	y	y	y	Yes				
6	NEYVELI LIG. CORP. LTD.	210	36	41	y	y	y	y	Yes				
7	NPCIL	210	35	40	y	y	y	y	Yes				
8	NPCIL	600	12	17	y	y	y	y	No	y	y	y	y
9	TN GEN. & DIS. CORP. LTD.	210	31	36	y	y	y	y	Yes				
10	TN GEN. & DIS. CORP. LTD.	210	30	35	y	y	y	y	Yes				
11	TN GEN. & DIS. CORP. LTD.	210	29	34	y	y	y	y	Yes				
12	TN GEN. & DIS. CORP. LTD.	1200	11	16		y		y	No				
18	TN GEN. & DIS. CORP. LTD.	210	46	51	y	y	y	y	Yes				
19	TN GEN. & DIS. CORP. LTD.	210	45	50	y	y	y	y	Yes				
20	TN GEN. & DIS. CORP. LTD.	210	43	48	y	y	y	y	Yes				
21	TN GEN. & DIS. CORP. LTD.	210	33	38	y	y	y	y	Yes				
22	TN GEN. & DIS. CORP. LTD.	210	34	39	y	y	y	y	Yes				
23	NEYVELI LIG. CORP. LTD.	350	14	19	y	y	y	y	No		y		y
24	NEYVELI LIG. CORP. LTD.	170	55	60	y	y	y	y	Yes				
26	NEYVELI LIG. CORP. LTD.	472	39	44		y			Yes				
27	NEYVELI LIG. CORP. LTD.		38	43		y			Yes				
28	NEYVELI LIG. CORP. LTD.		37	42		y			Yes				
29	NEYVELI LIG. CORP. LTD.		34	39		y			Yes				
30	NEYVELI LIG. CORP. LTD.		33	38		y			Yes				
31	NEYVELI LIG. CORP. LTD.		33	38		y			Yes				
32	NEYVELI LIG. CORP. LTD.		32	37		y			Yes				
34	NEYVELI LIG. CORP. LTD.	414	10	15		y			No				
35	TAQA NEYVELI	250	23	28	y	y	y	y	No	y	y	y	y
					4400	6872	4400	5986		850	1200	250	1200
					Capacity Unutilized					Capacity Unutilized			
					1200	3880	1200	2866					
					Capacity reconsidered								

Note: Unutilized plant under optimal case is same as low RE case

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