ELECTRICITY MARKET REFORMS FOR THE EFFICIENT PROCUREMENT OF ANCILLARY SERVICES

The electricity landscape in India is evolving rapidly. The government is committed to increasing the share of non-fossil fuels in the electricity mix to 50 percent by 2030. Increasing the share of renewables in the electricity mix will make the power system more sustainable. However, the efficient integration of renewables in the grid can be rather cumbersome without suitable balancing resources.

India's policymakers, regulators and industry experts are committed to energy and ancillary service (AS) market reforms in response to the increasing share of weather-dependent variable energy resources in the generation mix. Although the full nature and timing of reforms are still under discussion, there is broad industry consensus that Regional Load Dispatch Centres (RLDC) or State Load Dispatch Centres (SLDC) will need more operational flexibility from resources to reliably serve loads.

Responding to these changes to the resource mix requires market reforms, including the provision of appropriate price signals to attract investment in the balancing or flexible generation capacity. Remuneration for services and products should not only reflect the operational needs of the system, but also incentivise resources to participate in the energy and ancillary services market to provide operational flexibility to the system. Moreover, the remuneration structure should also encourage investment in flexible technologies and retirement decisions for inflexible power plants.

This report makes a case for market reforms in India using power system simulation models (expansion planning and unit commitment models (UCMs)):

(a) First, the report recognises that renewable energy (RE) targets set by the government (450 GW by 2030) need to be supported by investment in flexible generation technologies (thermal balancers and battery storage) and market reforms that enable the development of a resilient grid. KPMG's capacity expansion planning model (CEPLAN) determines the operational flexibility needed to cost-effectively integrate renewables into the system under a centralised dispatch mechanism (market-based economic dispatch, or MBED).

(b) Second, the states currently follow decentralised dispatch and are required to manage their area control errors. KPMG's UCMs are used to determine how thermal balancers and battery energy storage systems (BESS) could help the states to better manage their power systems and reduce operational costs.

(c) Finally, effective market reforms are critical for attracting investments in thermal balancers and BESS.

Capacity markets are proposed, in tandem with markets for energy and ancillary services, where the latter two are co-optimised. The co-optimisation of energy and ancillary services is shown to yield commercially attractive value (revenue) streams to attract thermal balancers and battery storage systems in the resource mix. This also highlights the effectiveness that such market reforms can offer in terms of unlocking the benefit that flexible generation capacities can provide. The following are some of the key takeaways from the study.

The current market structure lacks the resources for managing imbalances efficiently at the state boundary. The incentive structure needs to be further strengthened to encourage investment in flexible resources for imbalance management…

RE resources are concentrated in a few states in India. The existing power system governance framework requires each state to manage its power system and interchanges with the inter-state grid within limits. This has many implications. In Karnataka, SLDC reports planned RE curtailment of up to 25%, primarily in RE-heavy months. A recent paper by the International Energy Agency shows that a sustained 10% drop in the utilisation of RE capacities causes a 5% decline in the internal rate of return. This hampers new investments and puts the achievement of the national RE target at risk. RE-rich states like Rajasthan and Tamil Nadu pay charges on deviation (from the schedule) of more than INR 1 billion in a year. States like Gujarat operate inefficient power plants to manage supply intermittency. These strategies not only impose a financial burden on these states, but also put the national grid at risk. There is a need either to have flexible generation and storage capacities within the state for imbalance management or to keep overdrawal (OD) and underdrawal (UD) by the state utilities and other grid-connected entities within limits. It is recognised that the deviation settlement mechanism (DSM) is a penal mechanism for grid violation and such a mechanism should be considered neither as a substitute for thermal balancers and BESS nor as appropriate for providing signals for such investments. Flexible resources must be planned, and procured, through markets. The regular curtailment of RE generation and load shedding to manage the intermittency of RE capacities in several states indicate the need for operational flexibility.

Even with large balancing areas facilitated by the MBED mechanism, investment in flexible assets is required to accomplish reliable grids…

The study demonstrates that India's power system could be free from any coal-fired capacity additions beyond those that are already planned and still meet 340 GW peak demand as estimated by the Central Electricity Authority (CEA) for 2030:

(a) India's power grid could immensely benefit from using both internal combustion gas engines (ICE) and battery storage for meeting the flexibility requirements. The results indicate that by 2030 India would need 38 GW of four-hour battery storage and 9 GW of ICE for a cost-efficient and reliable integration of 450 GW of RE.

(b) More than 35 GW of wind and solar capacities should be consistently added annually between now and 2030.

Higher flexibility reduces the cost of power in the system by enabling the full dispatch of low-cost generators while ensuring grid resilience…

As the states self-schedule and manage their control areas, flexible assets and BESS will immensely help them, even now in 2021. Batteries and ICE have different characteristics and their use can optimise the utilisation of conventional fossil fuel-based assets. Simulations show that batteries support the grid by providing ramping support during morning and evening hours as the solar generation ramps and supply peak energy. In addition, BESS also provides three ancillary services; regulation up, regulation down and spinning reserves. Thermal balancers such as ICE provide contingency (non-spin) reserves, imbalance management during peak hours, and support for the ramping needs of the system during morning and evening hours. BESS and thermal balancers improve the system resilience of weather-dependent power systems during times of renewable drought. Such unique differences in how different flexible technologies are utilised in the system emerged more clearly from the modelling of Gujarat, Rajasthan and Tamil Nadu. The following are some of the key takeaways from the state-level model:

(a) The need for fast ramping technologies in the existing system is visible and the demand for such technologies will further increase. BESS and ICE are technologies that can effectively meet this demand.

(b) The augmentation of existing systems in these states with ICE and BESS enables better utilisation of the conventional plants. This reduces the variable costs of operation and heat rate degradation for conventional thermal plants. With BESS and ICE, the number of cycles in daily operations of conventional plants, such as coal and gas turbines, can be reduced. This not only significantly saves costs, but also reduces the plants' lifecycle costs.

(c) ICE ensures the availability of fast ramping resources to provide mostly non-spinning reserves and imbalance management. BESS is effective for energy shifting applications, spinning reserves and providing support during peak times.

(d) The benefits of flexible technologies are more pronounced in power systems with inflexible legacy assets. It is observed from the simulations that regions with less flexible technologies, such as Rajasthan and Gujarat, can unlock savings by introducing BESS and ICE in the power mix.

(e) The study shows that the average cost reduction using BESS could be approximately **INR 50 million/day**[1]. Savings in variable costs pay back the capital investments in these technologies within **6–10 years**.

Resource adequacy needs a clear definition, and state utilities need to have a resource adequacy plan. Capacity payments will be key for attracting the right resources. Centralised or regional procurement helps to lower costs…

Attracting investments in flexible generation technologies will need an enabling market design (structure). A well-structured resource adequacy framework is being conceived by the Ministry of Power (MoP). Capacities serve four purposes: (a) meet energy demand, (b) satisfy peak requirements, (c) meet reserve requirements and (d) provide flexibility, i.e. ramp products, frequent starts and stops where minimum uptimes and downtimes are not onerous and a low technical minimum. A policy framework that requires each utility to demonstrate resource adequacy is critical for a reliable and resilient power system. Procurement of such resources by individual states will not be efficient. Regional or national-level capacity markets will help to avoid the development of over-capacities and aid system reliability. This study shows that:

(a) If the states were to individually procure these capacities, the variable cost savings would pay off the capital investments in less than 10 years.

(b) Coordinated procurement by states, at least at the regional level, could significantly reduce the payback period. Coordination at the regional level ensures that states with high RE resources benefit from resources available in other states. This avoids resource duplicity and minimises the cost for utilisation of assets in each region. It also helps to plan resource adequacy at the lowest possible cost.

(c) A key enabling market design feature is proposed to include a capacity market (at least at the regional level) to procure balancing capacities. The capacity charges[2] for flexible technologies in 2025 are expected to be approximately

1 Using 4-hr. BESS (500 MW for Gujarat, Tamil Nadu and Rajasthan in 2021) and ICE (1000 MW, 700 MW and 1000 MW for Gujarat, Tamil Nadu and Rajasthan respectively in 2021), the cost savings could be around INR 46 million/day, INR 32 million/day and INR 70 million/day in Gujarat, Tamil Nadu and Rajasthan respectively.

2 The capacity charges include return on equity, interest on debt, interest on working capital and depreciation. The debt-to-equity ratio is considered to be 7:3.

INR 7 million/MW for ICE and between INR 10–16.5 million/MW for BESS. The capacities will need to be procured by the distribution utilities. Any shortfalls closer to real time will be procured by the regional system operators., The costs of procuring balancing capacities in the real time can be allocated based on causer pay principle to the distribution utilities whose initial procurement is deficient.

A co-optimised energy and ancillary services market is more efficient than separate markets for energy and ancillary services…

The demand for reserves is typically realised in the day-ahead and real-time markets. Most of the reserves are provided by resources that are also capable of providing energy. These services can be either sold separately or co-optimised. Since the same generating asset can provide both of these services, co-optimisation benefits both the generator that provides energy and ancillary services and the power system. The power system benefits because the system operator schedules the optimal combination of energy and ancillary services to minimise the total operational costs for the system. The generators benefit because the same generating asset can be optimally utilised for different value streams (ancillary services and energy). The separate procurement of energy and ancillary services essentially delinks services that are otherwise intrinsically linked and hence is a sub-optimal market design option. The simulations for 2021 indicate the prices of energy and the opportunity value of four types of ancillary services – regulation up, regulation down, spinning and non-spinning, which are provided in Figure 1. These prices are obtained with a co-optimised energy and ancillary services market where minimising the cost of reliable energy provides attractive value streams for investment. Coupled with capacity markets, the simulations indicate that the proposed market design can enable a smooth transition to a reliable green power system in India.

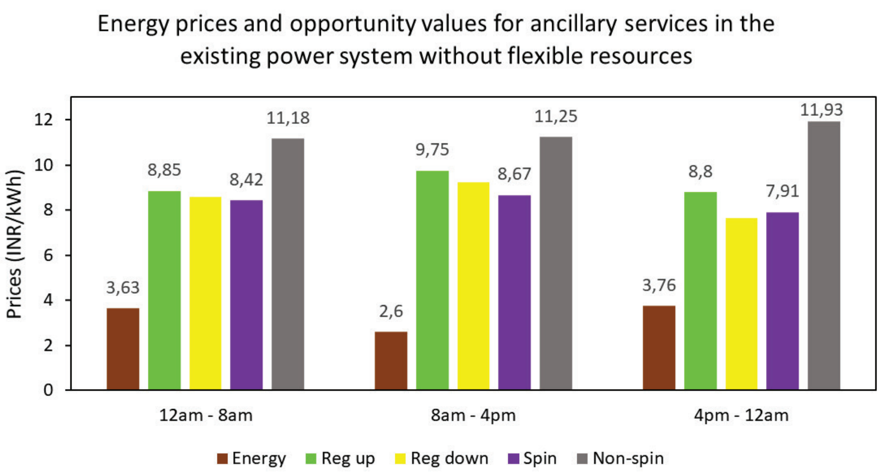


Figure 1: The average energy prices and the opportunity values for different AS over India at different times of the day is provided in the above figure. The simulation study is run on the existing system, without any flexible technology, while co-optimising the procurement of energy and ancillary services.

CONTENTS

1. THE NEED FOR ANCILLARY SERVICES IN INDIA AND MARKET DESIGN CONSIDERATION

Power system planning paradigms have evolved globally – earlier, conventional generation capacities used to be a fulcrum of the power systems, whereas now the focus is on integrating RE technologies. As a part of the Intended Nationally Determined Contributions, India plans to achieve 450 GW of RE capacity by 2030. Due to high variability in RE, a lot of challenges are introduced in the system with high RE penetration. The system needs to have flexibility and storage resources to manage imbalances and reserve requirements.

1.1. Existing AS reserve and imbalance management in India

In India, a structured methodology for reserve management is evolving. Although three segments of the ancillary service market are defined in the existing regulations, only slow tertiary is active. Mostly, thermal plants are utilised to meet the reserve requirements. As the Central Electricity Regulatory Commission (CERC) stated [17], each state control area needs to keep only 50% of the largest generating unit as tertiary reserve ancillary services (TRAS). The New York Independent System Operator (NYISO) mandates the maintenance of operating reserves at least equal to twice the largest contingency defined by NYISO and spinning reserves to be kept at least equal to 50% of the largest contingency [3]. Similarly, the California Independent System Operator (CAISO) mandates that spinning reserves must be no less than 50% the operating reserve required for each settlement period in the day-ahead market [1,15]. The operating reserves must be equal to the largest contingency in the area under CAISO guidelines [15].

The gate closure of the real-time market happens 1.5 hours before the real-time commitment, after which states cannot buy or sell power. Close to real-time DSM (OD and UD) is the only way to manage the imbalances for which states incur penalties. Sometimes, states exploit the DSM mechanisms for gains, which compromises grid stability.

Due to the installation of more weather-dependent RE capacities and loads, the need for ancillary services is growing. Moreover, AS providers need to respond quickly if there is an imbalance in the system. Due to technical limitations, keeping AS from traditional coal or gas plants is no longer a viable option.

1.2. Draft AS regulations are a step in the right direction, but more is needed

CERC recently published draft AS regulations [5]. The draft regulations are mainly aimed at liberalising the tertiary reserve market, while activating the secondary reserve market. In [5], it is suggested that secondary reserve ancillary services (SRAS) are maintained at a regional level. However, the imbalances are caused at a state level and the need for SRAS can vary across states. Moreover, the requirements for AS need to be defined in terms of both the ramping and sustained energy need of the system at each location, which are also followed by various Independent System Operators (ISO) in the US.

1.3. A different approach is needed for structuring the AS market in India

Ancillary services need to be procured for each location by state utilities to satisfy their resource adequacy requirements. This requires an estimation of local reserve requirements that may also change temporally.

1.3.1. States need to procure adequate AS at the state control area level

The system needs to maintain adequate resources to meet the growing demand for energy and ancillary services. The system operator needs to maintain adequate flexible resources to meet this increasing requirement. The requirement depends on the location, historical demand and RE fluctuations, and critical load needs to be served at any given point in time.

1.3.2. Characteristics of AS to support RE penetration while maintaining grid stability

The ancillary services need to be procured from local resources that satisfy the requirements imposed on the system by the characteristics of the demand, the intermittence and variability of RE resources and another supply fleet. For SRAS, the service provider needs to respond within a few minutes. Similarly, the TRAS provider must respond within 15 minutes. The TRAS must be procured from both online and offline units equally. CAISO also follows a similar strategy [1].

Due to the low ramping rate and high minimum uptime and downtime, traditional plants are not suitable for providing AS. Moreover, the system operator may need to operate costly plants to meet system requirements, which increases system operating costs. Moreover, many coal plants need to operate at a lower utilisation, and consequently their heat rates are impacted. The system operator requires not only the maintenance of adequate resources, but also resources that can meet the technical requirements.

1.3.3. Incentives for investing in flexible technologies

The requirement for flexible generation and storage capacities within the states for imbalance management, or to keep OD and UD from (or injection into) the grid by the state utilities and other grid-connected entities within limits, is imminent. The system needs to have physical resources, such as flexible generators or BESS, and these requirements cannot be replaced by the DSM. The resources must be physically procured, and the markets to procure such assets need to be created to encourage investment.

1.3.4. Market design for procuring energy and ancillary services

The procurement of energy and ancillary services can be done separately or jointly via co-optimisation. If energy and ancillary services are procured separately, this essentially delinks these services which are otherwise intrinsically linked. This is a sub-optimal market design option because this can increase procurement costs. The energy and ancillary services procurement needs to be co-optimised in order to minimise the overall system operational cost and better utilise resources. Various ISOs in the US and the Australian Energy Market Operator [1, 3,16] also follow a similar strategy for procuring energy and various ancillary services. The generators benefit from this because the same generating asset can be optimally utilised for different value streams (ancillary services and energy).

1.4. The structure of this report and motivation

Wärtsilä has a global commitment to helping nations in their cause by supporting independent assessment of the low-cost and green transition of power systems. The study conducted by KPMG assesses the needs of the power system in India to support the renewable energy capacity target of 450 GW by 2030. As the power system transitions to an RE-centric generation fleet mix, market design changes will be imminent. Changes in system dispatch (MBED) and the introduction of AS markets have already been conceived by the MoP and the CERC. This study assesses the following through Indian power system simulations:

(a) The capacity mix that India would need by 2030 under the centralised dispatch mechanism.

(b) The capacities that selected states (Gujarat, Rajasthan and Tamil Nadu) would need to have to manage their power systems – ensuring minimum RE curtailment and load shedding and maintaining AS.

(c) The value streams for capacities that would provide AS under a market design with capacity markets and co-optimised procurement of energy and AS services.

2. LONG-TERM GENERATION PLANNING AND BALANCING CAPACITY REQUIREMENTS

The renewable capacity addition trajectory has already been set by the Government of India (GOI). India will have at least 450 GW RE capacity by 2030. Further, the government recognises the need of system operators to manage intermittency in RE-heavy systems through investments in BESS, and large area balancing through market design changes (proposed MBED mechanism). To ensure reliable supply, while gradually greening the grid, the government is considering the retirement of some of the old and inefficient coal-fired power plants (10,817 MW). The CEPLAN model developed at KPMG considers all these GOI plans and all unit commitment-related challenges that a system operator faces (technical minimum amount of generators, minimum uptime and downtime of generators, start-up and shutdown decisions, costs of generators and ramping constraints) to plan the Indian power system until 2030 using a dynamic mixed-integer linear programming model.

With a target of meeting 340 GW peak demand and 2,325 billion units (BU) energy demand by 2030, India will not need any further additions to the coal-fired power plant fleet beyond those that are already planned (~32 GW, and retirement of ~11 GW). To achieve this, India must consistently add at least 35 GW RE capacity every year until 2030, with supporting storage systems. In a weather-dependent power system, resilience is critical. There can be intermittent intra-day periods of serious RE drought for which reserves sufficient to cater to critical loads (e.g. hospitals, defence, internal security establishments, etc.) must be maintained. These resources must have critical attributes – very low minimum uptime and downtime, and they should neither be ramp nor energy-constrained, i.e., they must be capable of providing energy for extended durations besides very high ramp rates. The study suggests that India requires the addition of at least 38 GW of BESS and 9 GW of ICE by 2030. ICE seems to play a big role in managing RE intermittency. ICE provides energy during morning hours as the solar supply ramps up, and during evening hours when solar-based supplies wane.

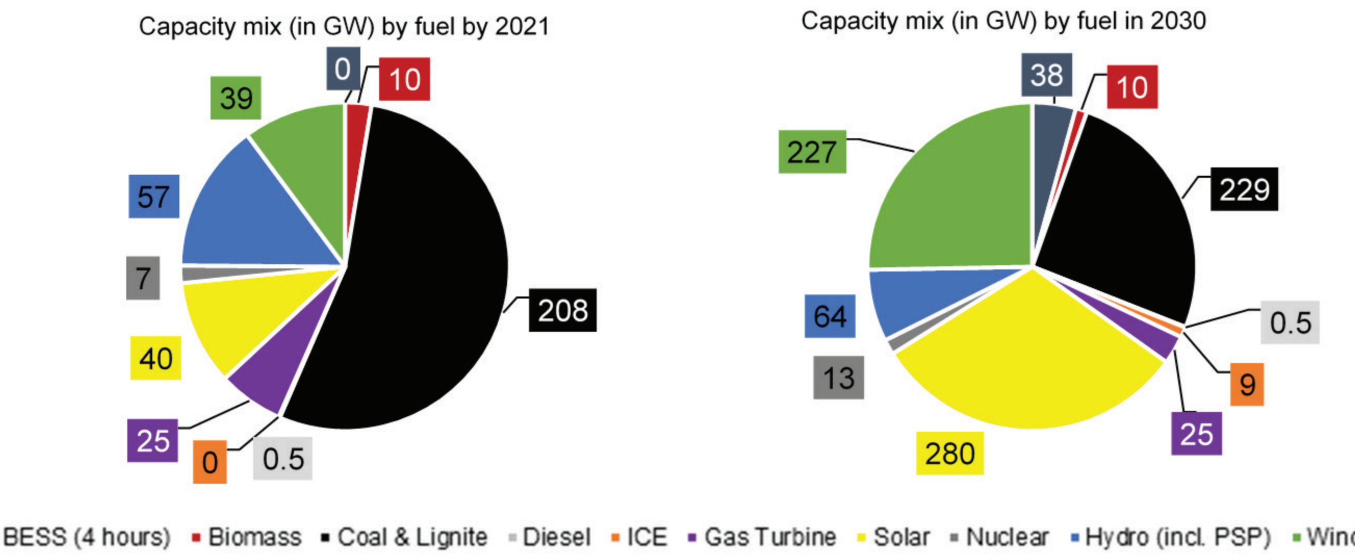


Figure 2: The capacity mix in 2021 and 2030 is provided in the above pie charts. Due to GOI initiatives to meet the INDC commitments, RE and BESS capacities will increase significantly by 2030, while the contribution of conventional technologies in the capacity mix will gradually decrease.

The study shows that India can have almost 66% of the installed capacity from non-fossil fuel-based plants by 2030, with adequate support from the storage and high ramping technologies, and meet its INDCs. Consequently, a significant change will be observed in the energy mix. The coal contribution will reduce by almost 35%, to be replaced by solar and wind, and the intermittence introduced by RE will be managed through hydro, BESS and ICE. The latter resources will also be used to maintain the reserve requirement. This will help in significantly reducing the emission intensity as well as total carbon emissions of the power sector.

Coal utilisation will drop significantly because many of the coal plants with higher variable costs do not need to operate under the centralised dispatch in the CEPLAN model. In 2030, the baseload requirement increases, which can be better served by the combination of nuclear, wind, solar and biomass plants.

In India, wind generation is higher during the evening and late-night hours and relatively less during the solar peak hours. To utilise the full RE penitential while ensuring grid security, the expansion of the transmission system also becomes imminent. Grid security will also be enhanced through AS provided by storage and high ramping technologies. Moreover, the study shows that it is beneficial to add more wind generation with proper technologies (BESS and ICE) in place, since this eliminates the need for any fossil fuel-based capacity to meet demand during non-solar hours.

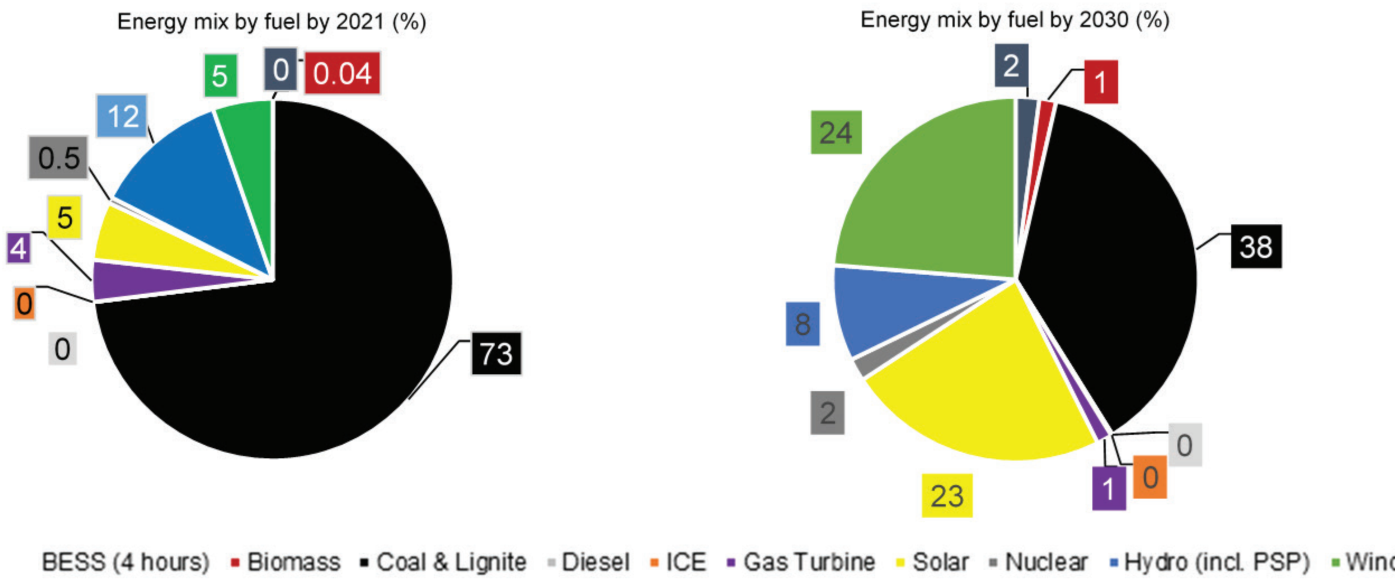


Figure 3: Various fuel types' contributions in the energy mix, by percentage, for 2021 and 2030 are provided in the above pie charts. As the capacities of solar, wind and BESS increase over the years, the contributions of RE and BESS will increase in the energy mix. The RE penetration with appropriate storage and ramping technologies helps to utilise solar and wind generation more effectively. As a result, coal utilisation and carbon emissions will be reduced.

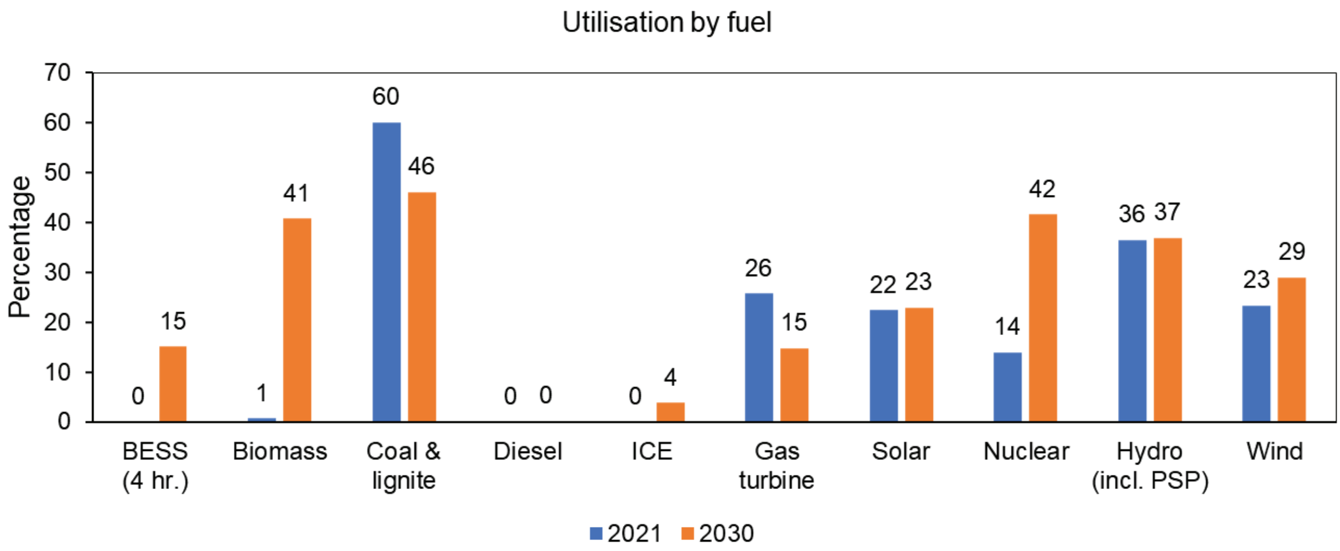


Figure 4: The utilisation of plants for various fuel types in 2021 and 2030 is provided in the above figure. The utilisation of biomass and nuclear plants will increase significantly by 2030 as the baseload requirement increases. Coal and gas turbine utilisation will decrease.

The states and union territories (UT), such as Delhi and Pondicherry, do not have sufficient state-owned generation. Low capital expenditure (CAPEX), high flexibility, short installation duration and modularity make ICE one of the best choices for maintaining adequate reserves while fulfilling the energy needs for these states and UTs.

For most regions in India, peak demand is observed during the evening time when solar energy is not available. As GOI is pushing towards greening the grid, BESS helps to meet the peak demand by shifting the energy during times when there is surplus RE generation. As BESS is an energy-constrained resource, ICE aids BESS to meet the demand requirement during the late evening hours and before sunrise. This is predominantly observed in Andhra Pradesh, Karnataka, Maharashtra, Punjab and Rajasthan.

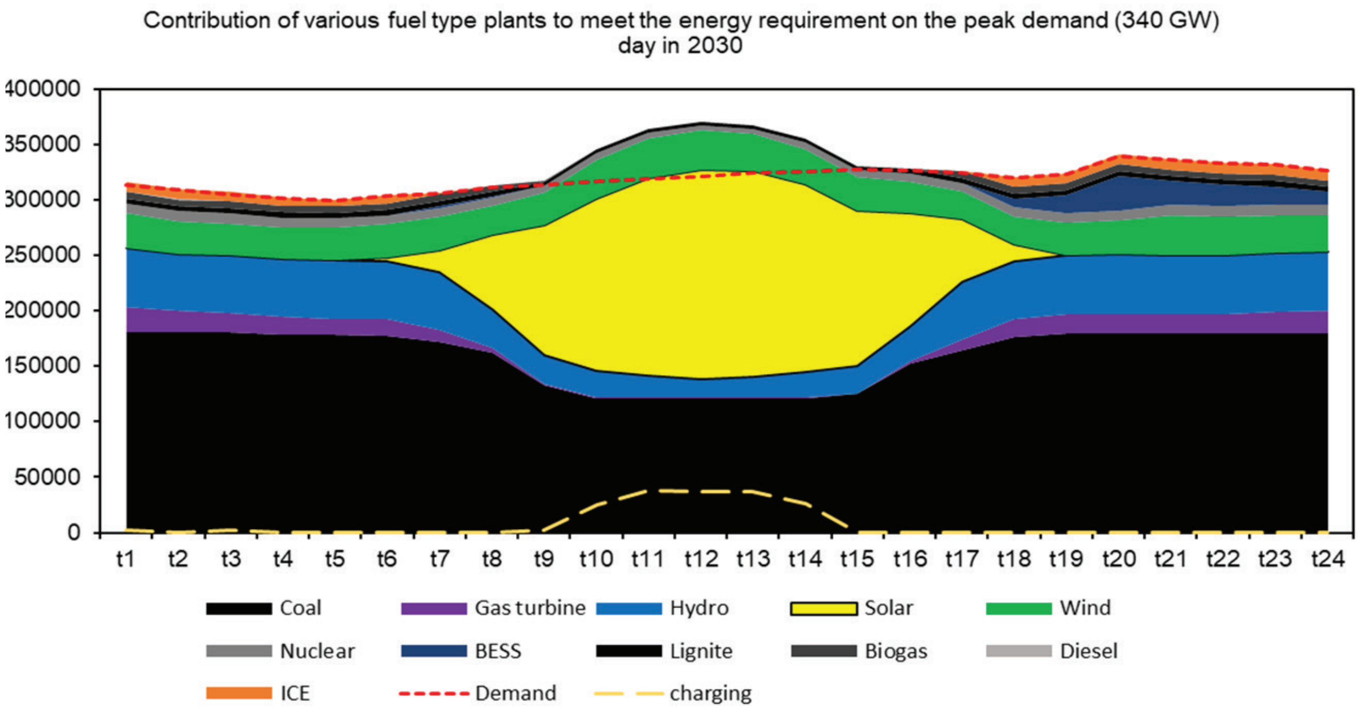


Figure 5: The above figure shows how the energy demand will be met by various fuel types on the peak demand day in 2030. Peak demand is observed at 8 PM. The coal plants back down and BESS charges during the solar peak hours. BESS discharges during evening hours, when solar ramps down, and later hours to meet the peak demand. ICE helps to meet the energy demand of the system when there is no solar generation. The same happens with gas turbine plants.

3. STRENGTHENING STATES' OPERATIONAL FLEXIBILITY FOR BETTER SAVINGS AND GRID RESILIENCE

3.1. State-level imperatives for integrating RE capacities

National-level capacity expansion planning models assume a centralised lowest-cost dispatch (MBED). However, under the existing institutional framework each state is required to dispatch its resources and submit scheduling requests for inter-state generators to the regional load dispatch centre. Here, three states (Gujarat, Rajasthan and Tamil Nadu) are simulated for selected days in 2021 and 2025 using a detailed Mixed-Integer Linear Unit Commitment programme developed at KPMG.

A national-level capacity expansion planning model (with unit commitment constraints built in) indicates that wide-area balancing – a seamless flow of power across states to balance the intermittency of renewable energy capacities – could delay the creation of balancing and reserve capacities. However, since seamless scheduling of resources across states is not possible under existing scheduling and dispatch frameworks, the presence of flexible technologies in the states (especially those with high RE capacities) will help not only to manage the power system better (area control errors), but also reduce the operational costs in these states. The savings in variable costs are such that the capital costs for balancing and ancillary assets could be paid back in 6–10 years. Therefore, under the existing institutional framework and processes that govern system operations in India, states need these flexible technologies today, and the need will only expand as more RE capacities are integrated.

The following unit commitment scenarios were simulated for the three states:

Scenario	Description	Motivation
Base case (scenario 1)	• Existing generators under state government and allocated capacities under PPAs, with central and private generating stations • Exchange prices as on days • Demand as on days • Existing solar and wind capacities and profile • Sufficient AS kept in the system	• Assessment of resource adequacy of the existing power system in each state • How AS and energy services can be managed with the existing infrastructure • Understanding the gap areas
Base case with flexible technologies (scenario 2)	• All assumptions are the same as in the base case • Additional 500 MW capacity battery with 2000 MWh storage and 10 units of 100 MW of ICE	• If BESS and ICE are installed with the existing infrastructure, how it can help to improve the overall system performance • Whether it is economically beneficial or not
2025 scenario with flexible technologies (scenario 3)	• Add the planned capacity with COD by 2025 and remove the capacity that is being retired by 2025 from the existing system • Solar and wind capacities as per government estimates • Demand profile scaled from 2021 to the forecasted demand by CEA • Two additional 500 MW 4-hour batteries and 20 units of 100 MW of ICE	• With high RE penetration, how the needs for AS will change • The roles of flexible technologies and BESS under this scenario

The state-level simulations indicate the following:

(a) The need for high ramping technologies in the existing system is visible and the demand for such technologies will further increase. BESS and ICE are technologies that can effectively meet this demand.

(b) Augmentation of the existing system in states with ICE and BESS enables better utilisation of the conventional plants. This reduces the variable costs of operation and heat rate degradation for conventional plants. With BESS and ICE, the number of cycles in the daily operations of conventional plants, such as coal and gas turbines, can be reduced, significantly saving costs and reducing the lifecycle costs of the plants.

(c) ICE ensures the availability of fast ramping resources to provide mostly non-spinning reserves and energy in some states. BESS is effective for managing imbalances, on-bar reserves and energy needs at peak times.(d)

The benefits of flexible technologies are more pronounced in power systems with inflexible legacy assets. It is observed from the simulations that regions with less flexible technologies (Rajasthan and Gujarat) benefit more in terms of cost savings by having BESS and ICE in their systems.

(e) The study shows that the average cost reduction using BESS and ICE could be around INR 46 million/day, INR 32 million/day and INR 70 million/day in Gujarat, Tamil Nadu and Rajasthan respectively.

3.2. Delving deeper into energy and AS dispatch

3.2.1 Impact on costs

Flexible technologies (BESS and ICE) reduce operational costs in all the states. In Gujarat, hydropower and biomass-based generation take over from costly coal/lignite and gas turbine-based generation in the presence of BESS and ICE technologies. In Tamil Nadu, hydropower plants, which, in the base case, are used for providing reserves, are used for providing energy and replacing costly and more polluting coal-fired generation. The reserves are provided by BESS and ICE technologies. In Rajasthan, morning peak is prominent and has been central to power procurement planning for a long time. BESS provides energy during this time, replacing purchases from outside the state or overdrawal from the grid. In all cases, ICE and BESS provide reserves.

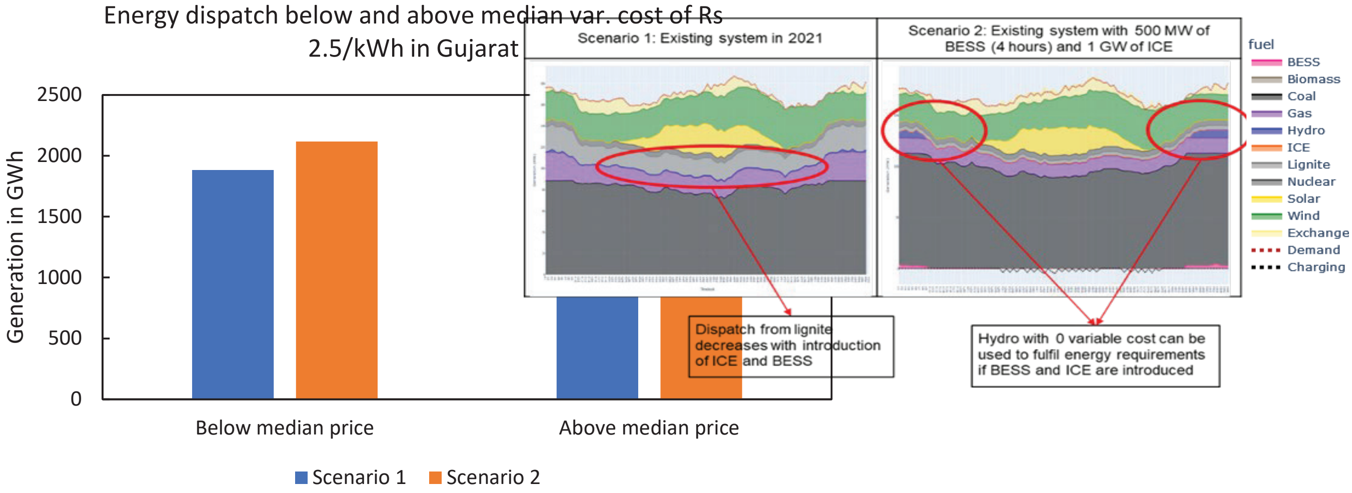


Figure 6: With the help of BESS and ICE, Gujarat can reduce the overall cost of the system by reducing the usage of expensive coal, lignite and gas turbine plants. Hydropower can be used during late-night hours to meet enegy requirements when the system operator is able to manage reserve requirements using other technologies.

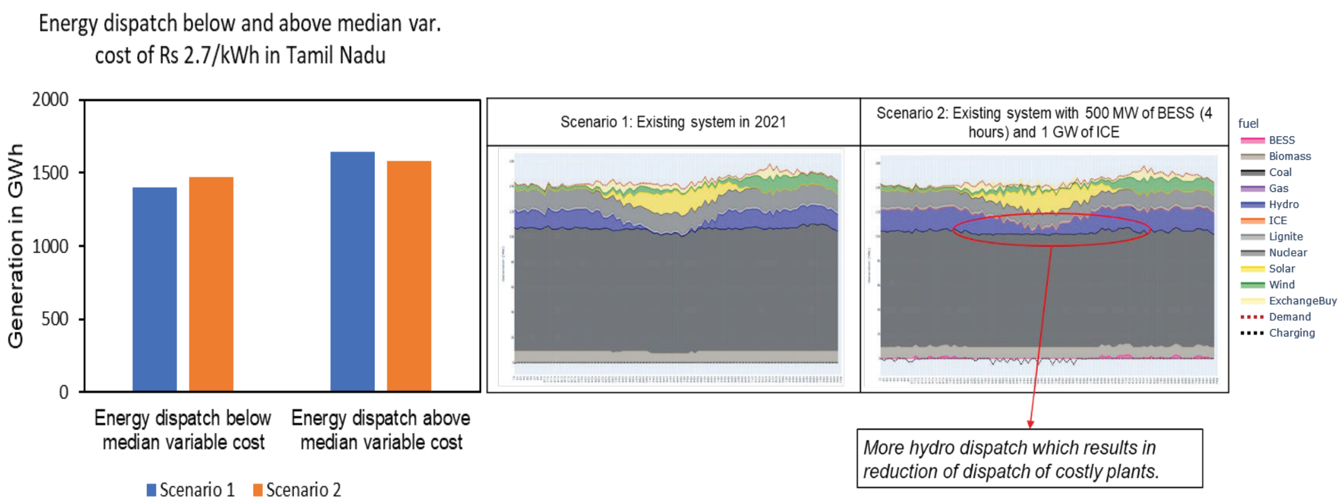
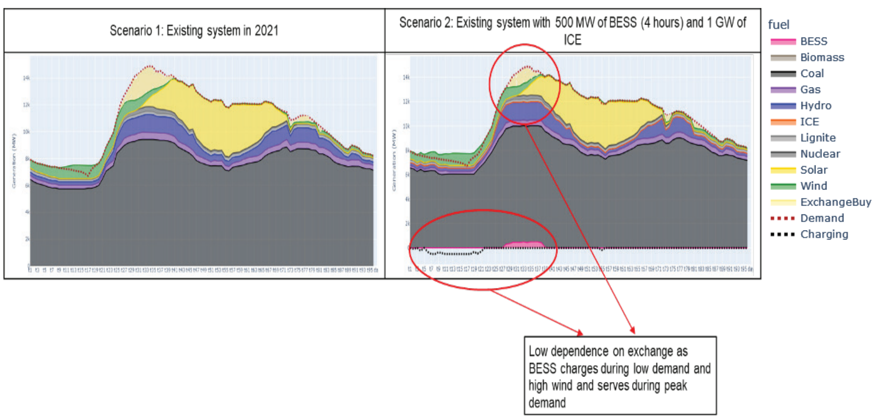


Figure 7: Tamil Nadu has a significant hydro capacity. Tamil Nadu needs to use the hydro capacity to maintain a reserve in absence of other flexible resources. If Tamil Nadu installs adequate BESS and ICE, then hydro capacity can be used to meet the energy requirements instead of procuring the energy from costlier plants and reducing the overall system cost.



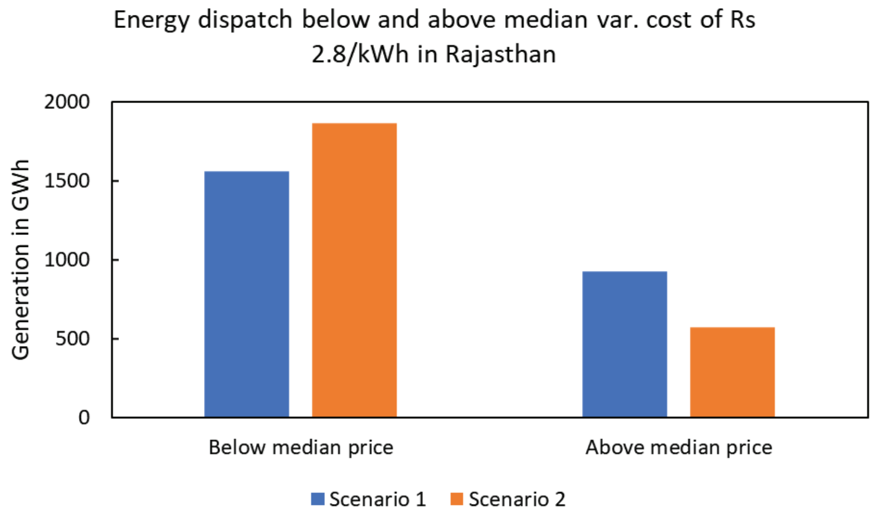


Figure 8: In Rajasthan, peak demand is observed during the early morning hours. BESS plays a crucial role in meeting peak demand requirements and reducing the overall system cost by shutting down expensive plants and reducing the need to purchase from the energy exchange at a higher price.

3.2.2. Utilisation of generation assets for the provision of AS

The presence of flexible assets allows all assets to be utilised for the purposes for which they are best suited. BESS and ICE enable better utilisation of conventional assets, and RE generators allow for the provision of energy. Peak load demand and reserves are taken care of by flexible technologies in all the states. Four types of ancillary reserve services are considered here: regulation up, regulation down, spinning and non-spinning reserves.

Any regulation reserve service provider needs to reach the declared capacity within five minutes and must be synchronised with the grid. The system operator needs to ensure that at least 2% of forecasted demand and 3% of forecasted RE are kept as regulation reserve services. CAISO, PJM and other ISOs follow a similar set of rules for keeping regulation reserves [1, 2, 3, 4]. As per the draft AS regulations [5], regulation reserves are required to provide the service for at least 30 minutes.

Operation reserve is procured equally from spinning and non-spinning reserve services. CAISO also follows the same rule [1]. The system operator needs to ensure that the maximum of the following amount is maintained as operation reserve (a similar set of rules is also followed by CAISO [1, 4]):

(a) The largest unit online in the system

(b) 10% of the forecasted load, i.e., critical load

Any operation reserve service provider needs to provide the service for at least one hour [5]. To provide a spinning reserve, the unit needs to be online and reach the declared capacity within 15 minutes [5]. On the other hand, the non-spinning reserve is provided by the offline units, which can come online within 15 minutes and reach the declared capacity [5].

The utilisation of assets for the provision of reserves and energy varies by state:

(a) In Gujarat, there is a lack of flexible resources. Installing BESS and ICE allows the shutting down of costlier plants. This reduces the utilisation of the traditional plants but makes effective usage of cheaper plants.

(b) In Tamil Nadu, the dispatch of hydropower plants increases in scenario 2, as a significant amount of reserve needs are served by flexible technologies (BESS and ICE). The coal utilisation for energy dispatch reduces due to the shutdown of some of the costlier coal plants.

(c) In Rajasthan, BESS provides spinning reserve, enabling better utilisation of cheaper coal. Also, when BESS is used for energy requirements, ICE provides spinning reserve.

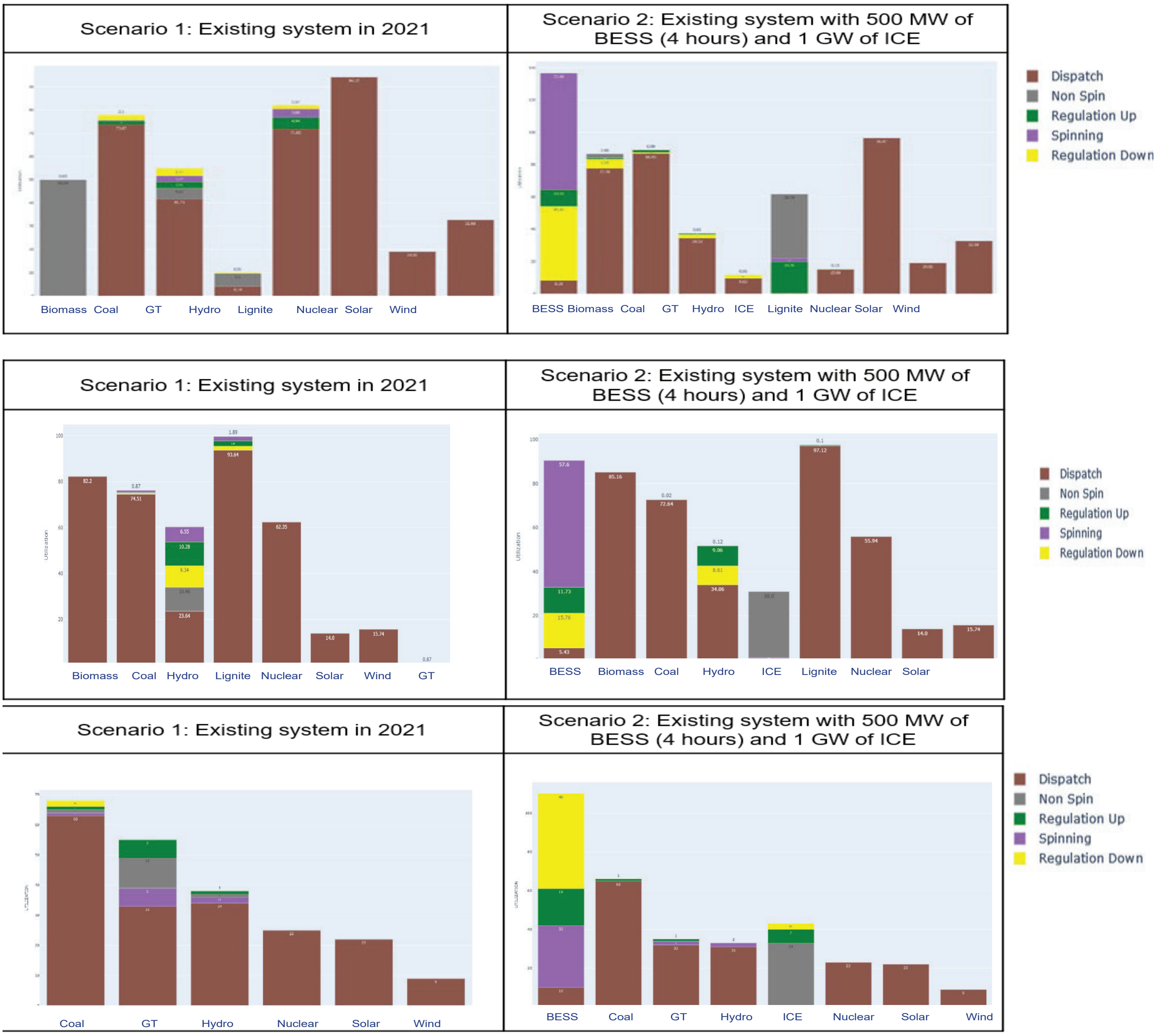


Figure 9: The utilisation of different technologies to provide energy, regulation, spinning and non-spinning reserve services is shown in the above figures for scenarios 1 and 2. The first set of plots are for Gujarat and the following plots are for Tamil Nadu and Rajasthan respectively.

3.2.2.1. Provision of regulation up and regulation down reserves

Regulation up reserves are provided by on-bar flexible gas turbines and coal plants. Since there is a requirement for very fast ramping ability to provide regulation services, a lot of coal plants are operated around the technical minimum to meet the highly inefficient reserve requirement. BESS can replace the need for coal to provide regulation reserve services. With fast ramping, ICE can provide regulation up services at times when BESS is occupied to provide energy and other AS, and this allows for coal plants to have better utilisation.

In CAISO, regulation up services are procured almost equally from gas, hydro, battery storage and imports, and gas has a significant contribution for providing regulation down services.

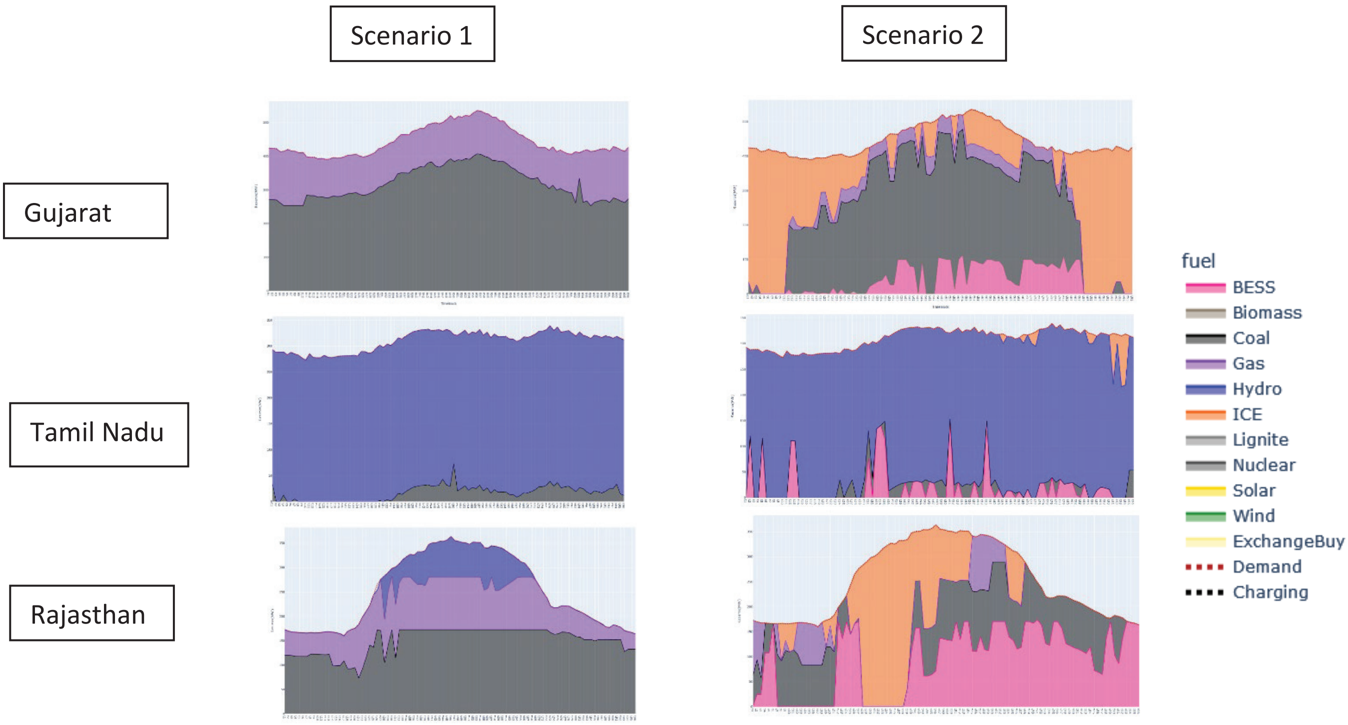


Figure 10: Regulation up services need to be provided within 5 minutes whenever required. In the absence of flexible technologies, the system operator needs to flex the coal plants, which leads to the operation of a greater number of coal plants at a lower utilisation. This leads to heat rate degradation of the plants and increases the overall operating cost of the system. Installation of BESS and ICE reduces the need for flexing coal to provide regulation up services.

3.2.2.2. Provision of spinning reserves

Spinning reserves are provided by coal and gas turbines, which must dispatch at least at technical minimum to serve reserves. This leads to more expensive plants operating, as well as lower utilisation of cheaper conventional technologies when flexible technologies are not operational. Spinning reserves are provided by BESS during high RE availability, and by ICE during low RE availability when BESS discharges to meet energy needs.

For all three states, it is observed that if BESS is installed with the existing system, the spinning reserve requirements are majorly served by BESS. Due to the flexibility (no technical minimum and high ramping rates), BESS is the best choice for providing spinning reserve services. This helps to shut down the costlier thermal and gas turbine plants, which are operated to provide the spinning reserves in scenario 1.

In Tamil Nadu, hydropower is used to provide the spinning reserve services in scenario 1. In scenario 2, the introduction of BESS in the system frees up this hydro capacity, which is further utilised to meet energy demand.

CAISO also keeps spinning reserve services, mainly from hydropower, battery storage and gas-fired plants [1, 9]. The simulation results suggest the same based on the available capacities of the corresponding state.

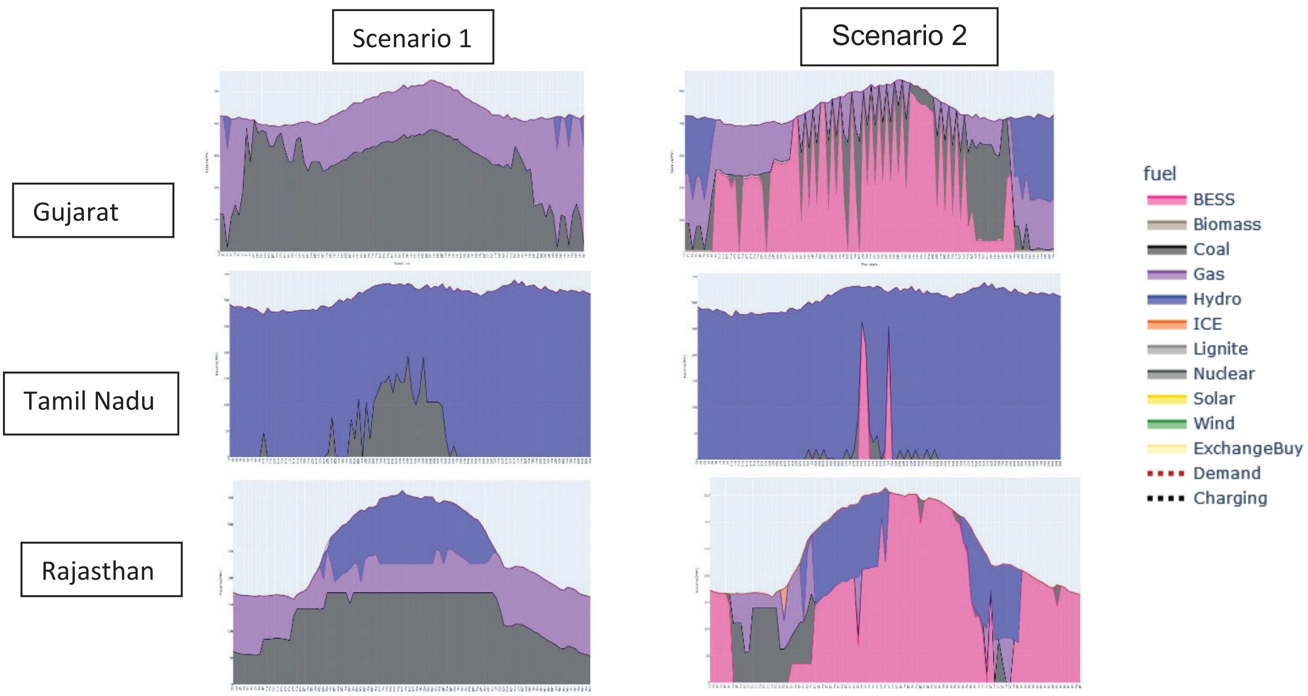


Figure 11: To provide regulation down services, the plant needs to have fast ramping capabilities as well as dispatch sufficiently above the technical minimum to be able to ramp down. During solar peak hours, when the coal capacities are already back down and operating at their technical minimum (or close to it), BESS is used as a regulation down service provider. In Gujarat and Rajasthan, BESS is used as a regulation down service provider almost throughout the day. However, Tamil Nadu can use its hydropower capacities to provide this service.

3.2.2.3. Provision of non-spinning reserves

Non-spinning reserves are provided by conventional capacities (including hydropower) in the base scenario without flexible technologies. The presence of ICE allows for the utilisation of conventional capacities to meet energy and peaking needs.

ICE is the best choice for non-spinning reserve providers due to its high ramping rates and lack of uptime or downtime and start-up or shutdown costs.

In scenario 1, the states need to procure non-spinning reserves mostly from the hydropower plants. However, the states where there are no (or limited) hydro capacities, such as Rajasthan and Gujarat, find it difficult to procure non-spinning reserve services, and most of the time they procured these services from coal or gas turbine plants, which is not advisable. If states installed adequate ICE, this would help them to maintain sufficient non-spinning reserves and reduce the overall system cost by freeing up hydropower capacities.

In CAISO, non-spinning reserve services are mainly procured from gas-fired plants [5], and the simulation results support this approach.

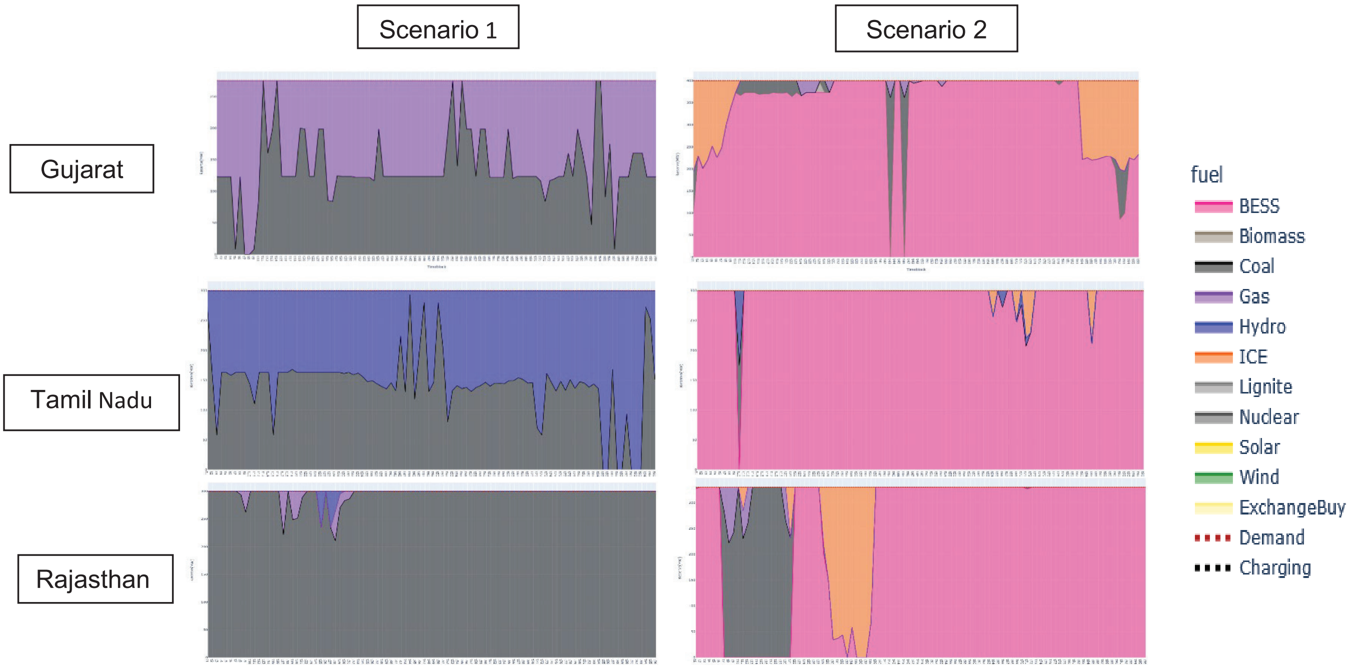


Figure 12: The spinning reserve contribution of various technologies for scenario 1 (left) and scenario 2 (right) is provided in the above figures. BESS provides the spinning reserve service almost throughout the day, which frees up the hydropower capacities to serve the energy demand and helps to shut down the expensive plants.

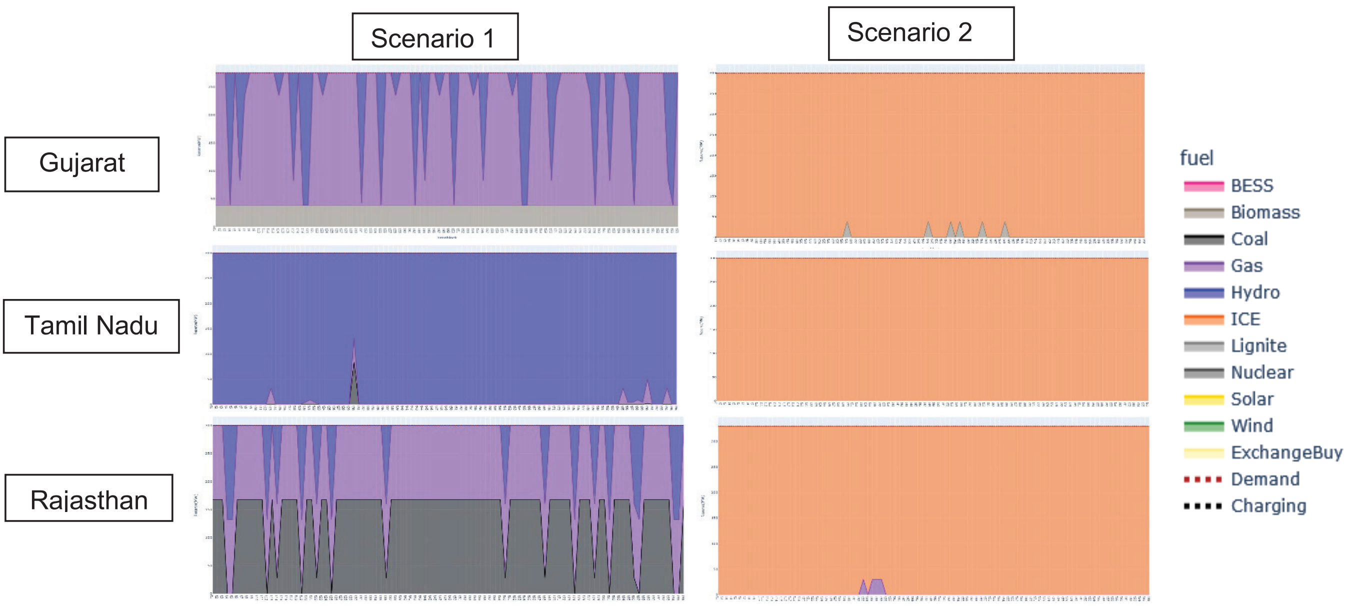


Figure 13: The non-spinning reserve contribution of various technologies for scenario 1 (left) and scenario 2 (right) is provided in the above figures. The states that have limited (or no) hydropower capacities find it difficult to maintain the non-spinning reserve requirements in the system. ICE aids this situation due to its flexibility. Moreover, hydropower plants need to be offline to provide non-spinning reserve services, but ICE can replace this need and free up the hydropower capacities to serve the energy demand and other AS (regulation and spinning reserve).

3.2.3. The need for storage and flexible technologies is growing with increased RE penetration

As the penetration of RE assets increases the value of flexible technologies does too, especially when inter-state flows are not seamless and the responsibility for maintaining cross-state flows within schedules lies primarily with the states. The simulation results presented here illustrate the importance of flexible assets in future (2025) power systems in Rajasthan, Tamil Nadu and Gujarat.

3.2.3.1. Gujarat in 2025

(a) During high RE availability, batteries store surplus energy to prevent the shutdown of conventional resources, thereby maintaining uptime and downtime constraints to meet energy needs during peak hours shortly after sunset.

(b) If Gujarat installs two 500 MW 4-hour battery storage units by 2025, these can be used to serve both spinning and regulation reserve services.

(c) ICE provides a constant 400 MW non-spinning reserve service with some dispatch due to steep RE ramping. Generally, this is dispatched when solar ramps up and down.

(d) Spinning and regulation reserves are mostly provided by BESS.

(e) BESS provides regulation up, except during dispatch times when it has to dispatch. It maintains spinning reserves owing to its low reserve holding cost, which is more economical for the model.

(f) ICE provides a non-spinning reserve due to its low start-up costs and high flexibility.

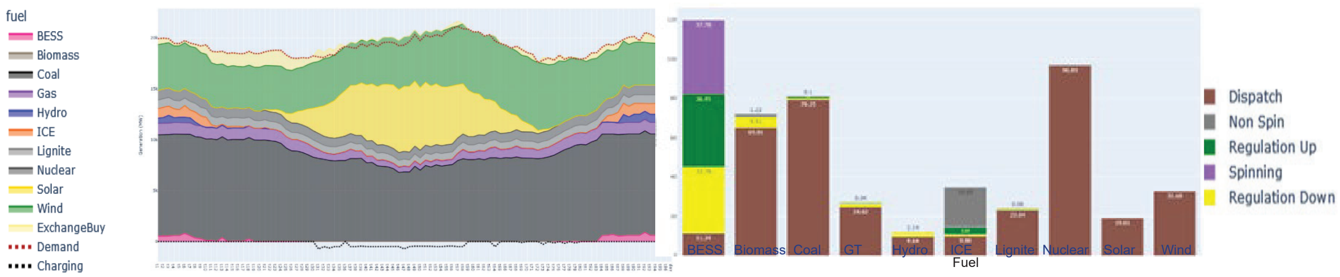


Figure 14: The figure on the left-hand side shows how the demand would be met by various technologies on a typical day in Gujarat in 2025. The figure on the right-hand side shows how various technologies are utilised to provide energy and various ancillary services.

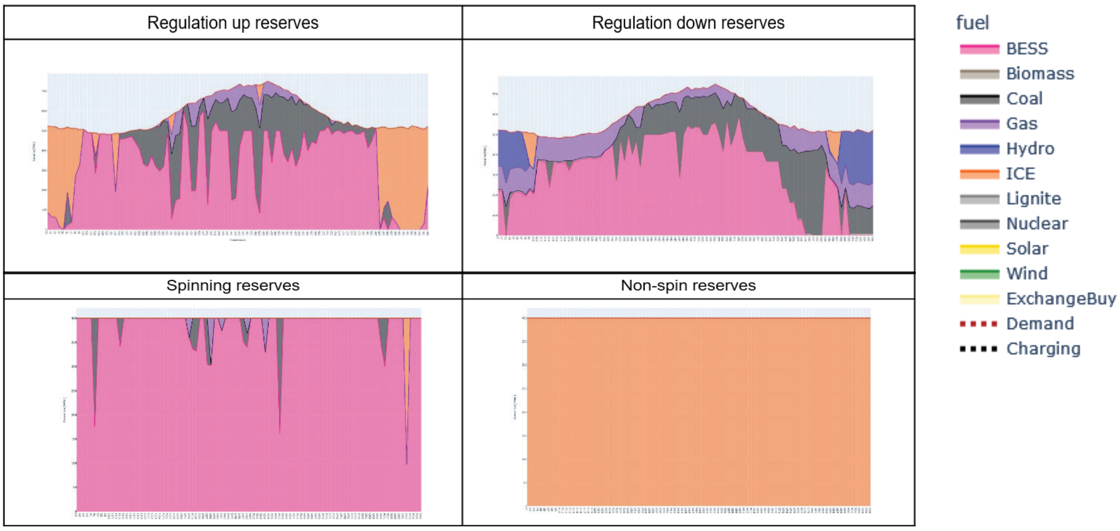


Figure 15: The figures above show how ancillary services would be provided by various technologies in 2025 in Gujarat. BESS provides a significant amount of regulation and spinning reserve services. The non-spinning reserve service is only provided by ICE. During late-night hours, ICE can also help to provide the regulation up service and meet the energy demand.

3.2.3.2. Tamil Nadu in 2025

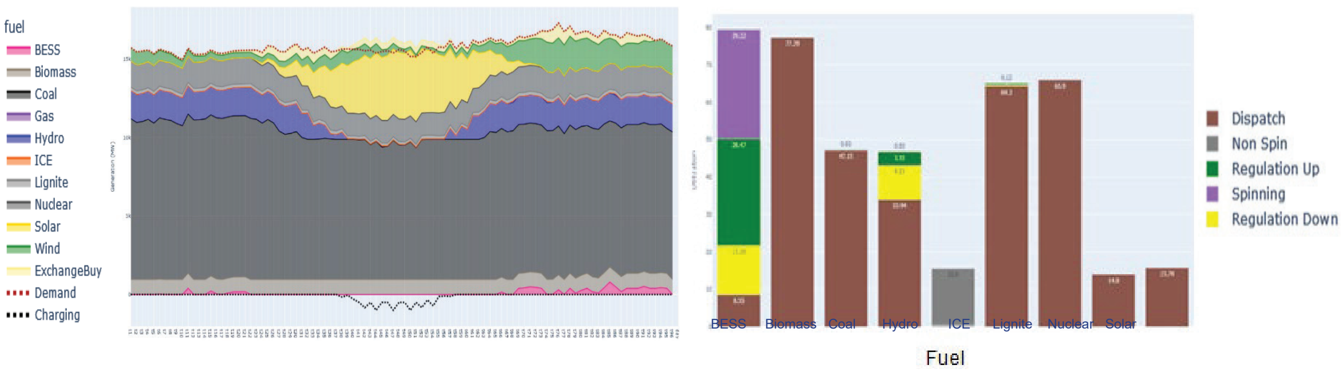


Figure 16: The figure on the left-hand side shows how the demand would be met by various technologies on a typical day in Tamil Nadu in 2025. The figure on the right-hand side shows how various technologies are utilised to provide energy and ancillary services.

(a) In 2025, BESS gives spinning as well as regulation up reserves, demonstrating the increasing requirement for BESS in the system.

(b) ICE provides constant 300 MW non-spinning reserves (15% of its total capacity), and during 2–3 blocks per day its total use (as an energy dispatch, spinning and regulation up service provider) goes up to 500 MW – even 700 MW at times.

(c) During high RE availability, the battery stores surplus energy to prevent the shutdown of conventional resources, thereby giving optimal system operation, keeping in mind the future needs of the system and the technical parameters of different technologies.

(d) BESS provides regulation up, except during dispatch times when it is exhausted by spinning reserves and dispatch.

(e) BESS also provides regulation down services during solar peak hours.

(f) ICE provides non-spinning reserves due to the low technical minimum, high ramping rates and zero up/downtime.

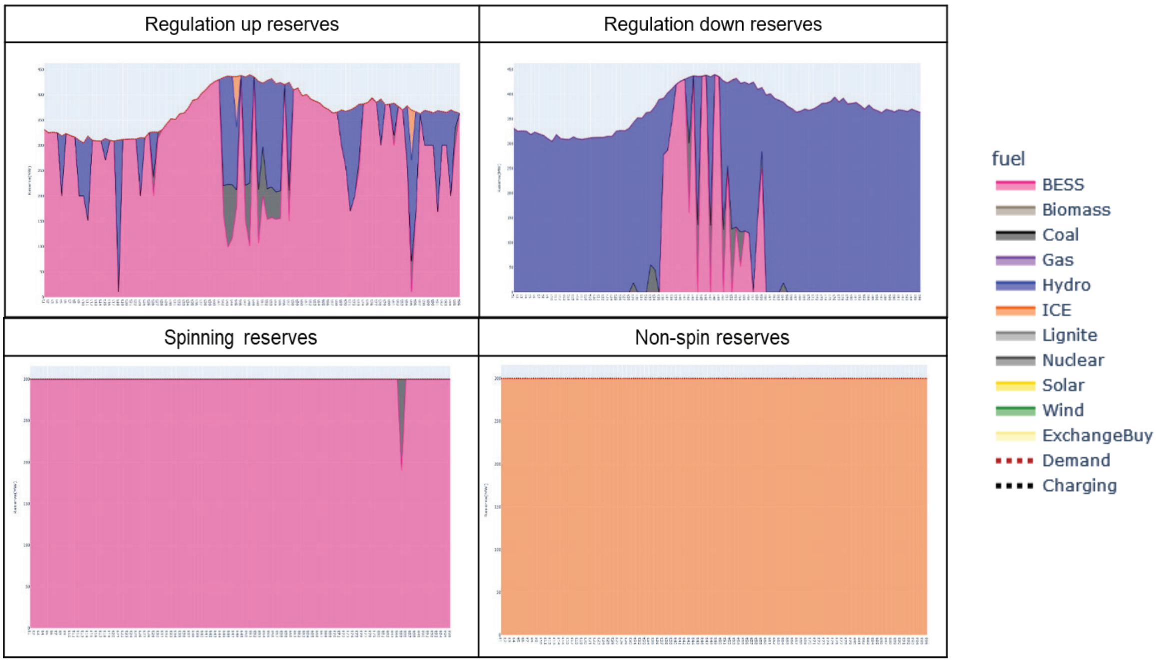


Figure 17: The figures above show how ancillary services would be provided by various technologies in 2025 in Tamil Nadu. BESS mainly provides a significant amount of regulation up and spinning reserve services, and occasionally regulation down services as well. The non-spinning reserve service is only provided by ICE. Regulation down services are mainly procured from hydropower.

3.2.3.3. Rajasthan in 2025

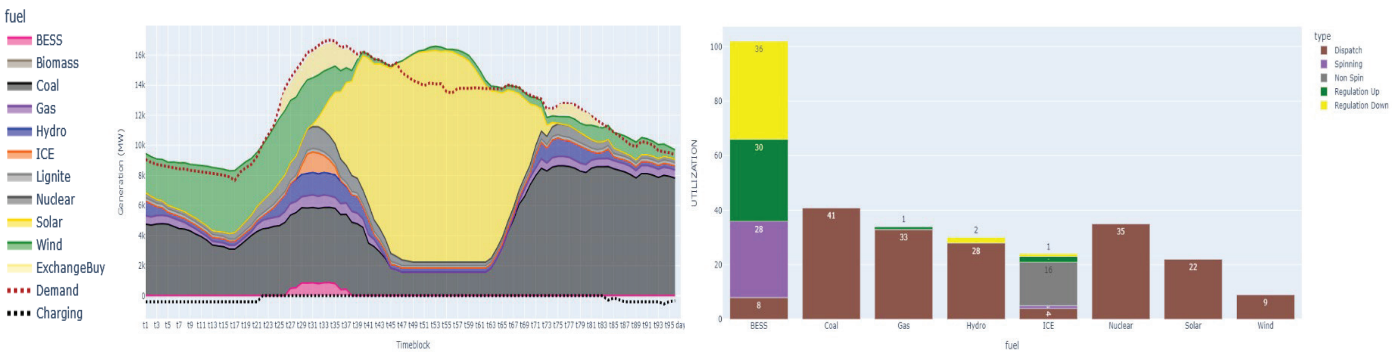


Figure 18: The figure on the left-hand side shows how the demand would be met by various technologies on a typical day in Rajasthan in 2025. The figure on the right-hand side shows how various technologies are utilised to provide energy and ancillary services.

(a) Rajasthan plans to install a significant amount (an additional 30 GW) of RE capacity by 2025. As a result, the need for coal and other conventional technologies is reduced and the requirement for flexible technologies increases.

(b) Peak demand in Rajasthan was observed at around 17 GW. Between 6–10 AM, BESS discharges to serve the ramping and peak demand needs of the system. ICE also contributes to the energy service when demand is high.

(c) During the morning hours, wind generation is almost negligible in Rajasthan. However, it gradually increases after sunset. BESS charges itself during between 8 PM–5 AM. In particular, in Rajasthan wind helps to charge BESS.

(d) The potential for BESS charging helps the system in keeping regulation down reserves. At times of peak solar, when conventional generation is at its lowest, only BESS can keep regulation down reserves and hence avoid charging from surplus power.

(e) Most of the regulation and spinning reserve services are provided by BESS.

(f) ICE supports BESS to meet the peak demand. However, ICE is mostly used to provide non-spinning reserve services. ICE also provides the spinning and regulation up services during peak demand hours.

(g) During solar peak hours, the requirement for regulation reserve services goes up. Due to high solar generation, coal plants need to back down and operate at their technical minimum. As a result, BESS is the only option for providing regulation down services. Hence, BESS is not charged during these time periods, although there is surplus generation in the system.

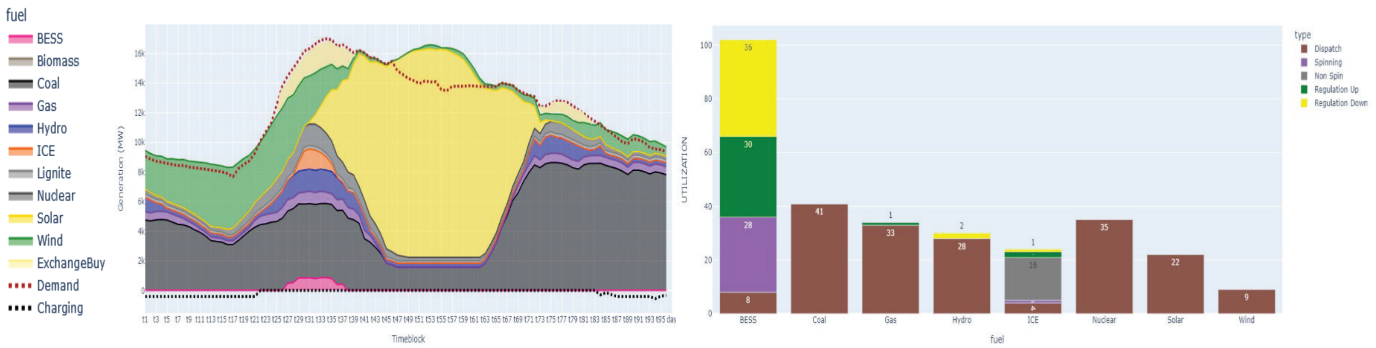


Figure 19: The figures above show how ancillary services would be provided by different technologies in 2025 in Rajasthan. BESS mainly provides a significant amount of regulation up and down and spinning reserve services. The non-spinning reserve service is mainly provided by ICE.

4. ANCILLARY SERVICES MARKET DESIGN FOR INDIA

4.1. The capacity market for meeting resource adequacy needs

The GOI is committed to meeting deep decarbonisation targets for the electricity sector in a cost-efficient manner, wherein reliability is a cornerstone. Several factors influence power system expansion and the choice of technologies for the generation fleet.

(a) First, achieving decarbonisation commitments by installing 450 GW of renewable energy capacity, duly supported by a large fleet of storage assets by 2030, will require considerable downsizing of investments in dispatchable coal-fired generators.

(b) Second, most wind and solar resources are found in only a few states, and the electricity transfer will require considerable investment in a strong transmission network.

(c) Third, electricity contracts between the renewable energy generators and various states aided by strong transmission networks will help to improve the ca(d) pacity utilisation factors of these generators by exploiting the diversity in demand and various balancing resources across the states.

(d) Fourth, coordinated planning and procurement to meet resource adequacy over a large area (beyond a state) create capacities that allow for the creation of larger wholesale markets or dispatch areas (beyond the boundaries of a state). This makes it possible to utilise wind and solar generating capacity more efficiently, reduce curtailments of wind and solar, decrease the quantity of generation needed to meet demand consistently within reliability criteria and reduce the need for storage, in turn reducing total bulk power system costs.

In keeping with the changing mix of the generation fleet, as driven both by the falling costs of new technologies and the decarbonisation imperative along with its attendant uncertainty, in the interests of securing a reliable supply procurers must plan resource adequacy from the following perspectives:

(a) capacities to meet energy needs

(b) capacities to meet peak demand

(c) capacities to meet fast ramping needs

(d) capacities to meet various reserve requirements, i.e., regulation up, regulation down, spinning and non-spinning reserves

A key starting point for contracting such capacities is to first estimate the demand for each of the above capacities in the long, medium and short terms. Further, given the geographic spread of potential and the availability of renewable energy resources, a strong transmission network must be built, along with the procurement of electricity from these generating capacities. While each distribution utility may plan individually, procurement at a regional level helps to avoid the development of over-capacities and aids system reliability.

This study shows that even if the states were to procure these capacities individually, the variable cost savings would pay off the capital investments in less than 10 years. However, coordinated procurement by states, at least at the regional level, could significantly reduce that payback period. Coordination at the regional level ensures that states with high RE resources benefit from resources available in other states. This avoids resource duplicity and enables the lowest-cost utilisation of assets in each region. It also helps in planning for lowest-cost resource adequacy. A key enabling market design feature would be to have a capacity market (at least at the regional level) for procuring capacities. The capacity charges for flexible technologies in 2025 are expected to be approximately **INR 7 million/MW for ICE** and between **INR 10-16.5 million/MW** for **BESS**.

4.2. A joint market: co-optimisation of energy and ancillary services

Co-optimisation benefits both the generator that can provide both energy and ancillary services and the power system. The power system benefits because the system operator schedules the optimal combination of energy and ancillary services to minimise the total operational costs for the system, while the generators benefit because the same generating asset can be optimally utilised for two different value streams (ancillary services and energy). Power system models are developed to simulate the co-optimisation of energy and ancillary services using a mixed-integer linear programming framework.

The simulation results presented here indicate the expected prices in the energy and AS markets for the years 2021 and 2025.

Scenario A: All-India UCM for 2021, with energy and reserve demand is considered. The list of existing plants is taken from [6]. The energy demand is considered as per the observed value on the day.

Scenario B: All-India UCM for 2025, with energy and reserve demand is considered. The energy demand for 2025 is aligned with the partial end-user method forecasted energy demand [7]. The list of thermal, nuclear and hydropower plants is updated based on upcoming planned installations and retirements [8]. The 2025 wind and solar capacities for the three selected states are adjusted based on their current installed capacities and GOI initiatives to install solar and wind capacity by 2025.

Scenario C: The flexible technologies, such as BESS and ICE, are added onto scenario B to assess the impact of such technologies on the prices of various services.

4.2.1. Energy prices in a co-optimised energy and AS market

It is important to recognise that once flexible technology capacity charges are paid (through the capacity markets or otherwise), variable costs are expected to be much lower and less volatile. This is one reason why a capacity and energy market-based design has been proposed, as opposed to an energy-only market.

(a) From 4 PM to 12 AM, energy prices increase across all scenarios because demand is high during the evening time and the system operator needs to schedule costly generators.

(b) However, flexible resources could help to reduce the energy procurement cost by freeing up the cheaper plants, which are otherwise engaged in providing AS.

(c) Energy prices decrease slightly from 8 AM to 4 PM due to solar availability.

)d) There is some RE curtailment observed in states like Karnataka and Tamil Nadu, which can be avoided when BESS and ICE are introduced into the system. With adequate storage and flexible technologies, the system can manage RE effectively.

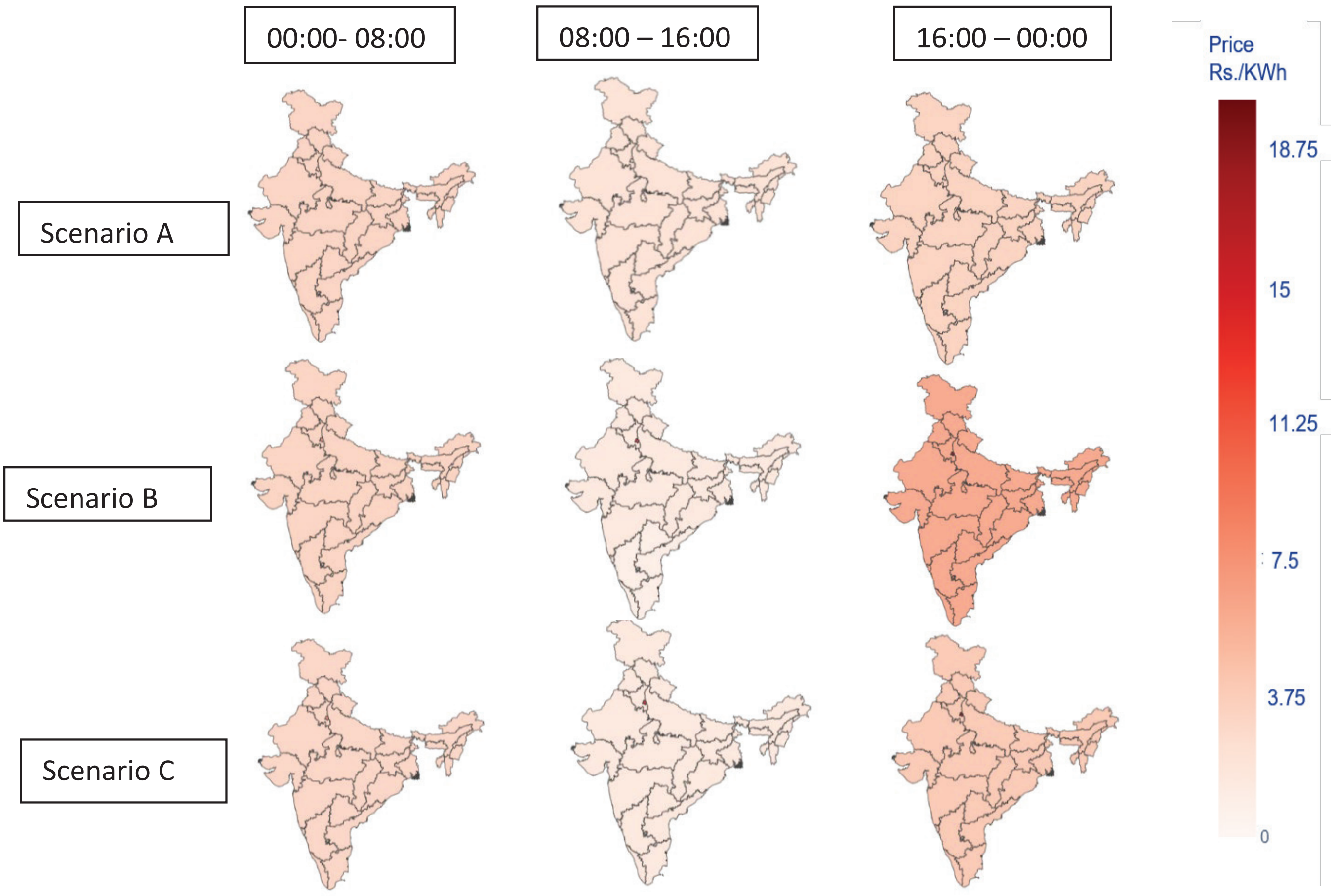


Figure 20: Energy prices for three different scenarios in the short-term markets are provided for three different periods of a day in the figures above. The darker colour represents higher prices. The lowest price was observed during peak solar hours and the highest during the evening hours. If scenario B is compared with scenario C, it can be seen that flexible resources help to bring down energy prices.

4.2.2. AS prices for regulation up and regulation down services in a co-optimised energy and AS market

States must have flexible resources to meet the need for regulation services. This also helps them maintain the regulation up charges within an affordable range.

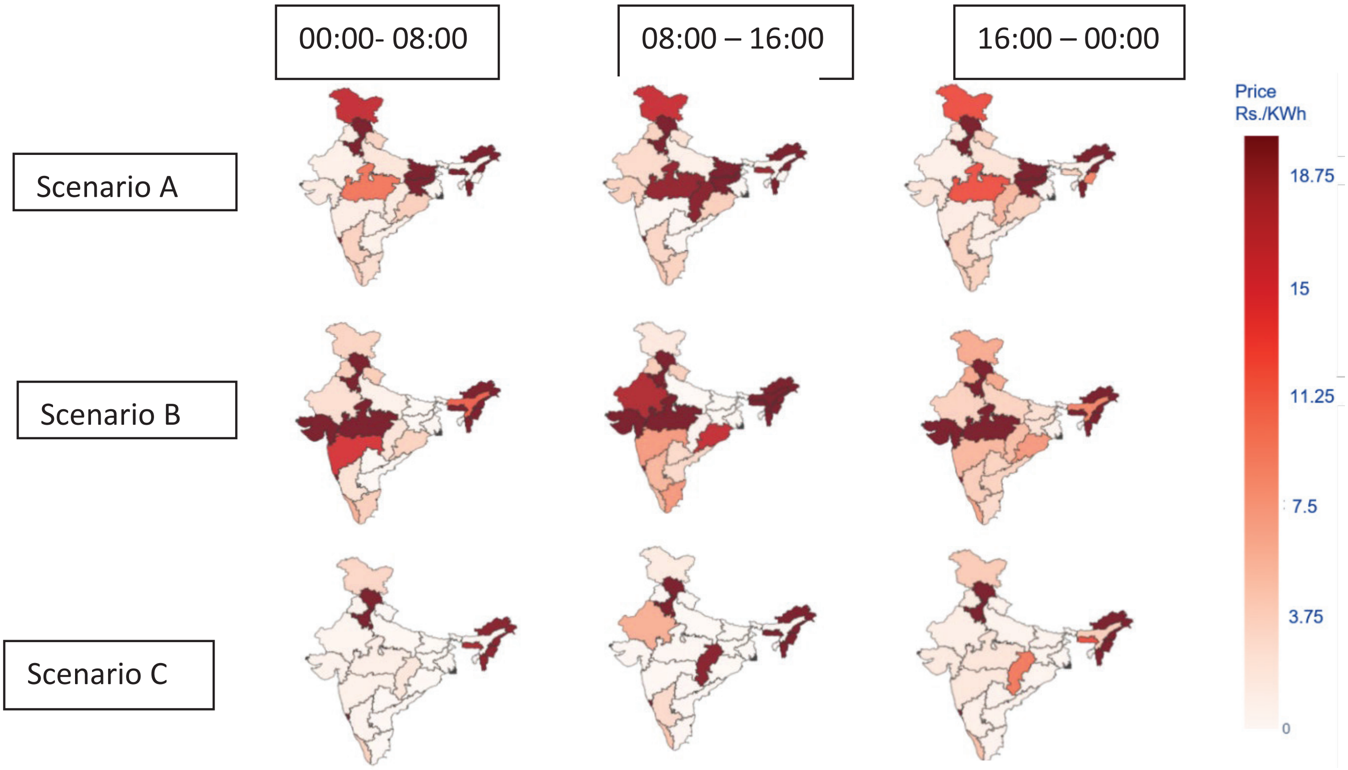


Figure 21: Regulation up prices for three different scenarios in the short-term markets are provided for three different periods of a day in the figures above. The darker colour represents higher prices. The maximum price for the regulation up service is observed during peak solar hours, due to the high demand for regulation up reserves. States that do not have fast ramping resources have higher prices. The inclusion of flexible resources in the generation fleet will help to bring prices down.

(a) States like Bihar, Nagaland and Mizoram do not have sufficient capacity, so regulation up prices in these states are generally high throughout the day.

(b) Regulation up prices are high from 8 AM to 4 PM when solar generation is high.

(c) Higher BESS capacity in states like Gujarat, Madhya Pradesh and Haryana could lower the price of regulation down services.

(d) Planned coal capacities in Bihar provide an opportunity for regulation down services in 2025.

(e) On the contrary, the price of regulation down services in South India in 2025 will be higher between 8 AM and 4 PM. A significant amount of solar capacity will be installed in South India by 2025. During solar peak hours traditional plants will back down, so there is no capacity to provide regulation down services. Otherwise, RE curtailment is required, which is not desirable.

(f) It is observed that the regulation down price is higher during solar peak hours throughout the year in CAISO [9], and a similar pricing trend can be seen in the simulation results.

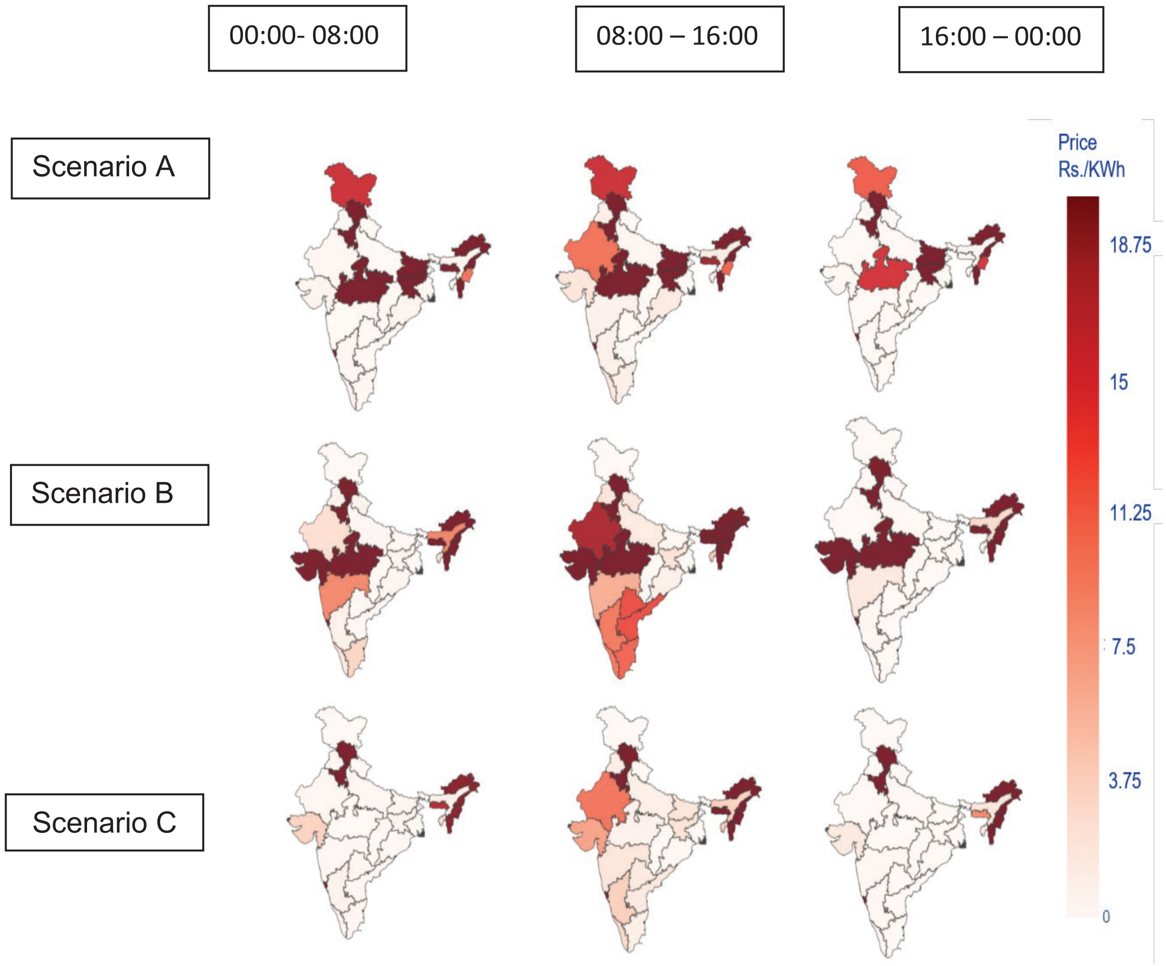


Figure 22: Regulation down prices: maximum prices are seen during peak solar hours, due to a high regulation reserve demand and conventional generators already being on backdown. Flexible resources such as BESS can help in regulating down reserves through charging.

4.2.3. AS Prices for spinning services in a co-optimised energy and AS market

States need to have the free on-bar capacity to provide spinning reserves. However, due to a lack of adequate flexible resources, high spinning reserve costs are observed in many of the states. Prices are highest during the night due to high demand and low RE availability. There is a strong correlation between energy and spinning reserve prices, which is also seen in CAISO [10].

(a) In 2025, there will be a significant rise in the price of spinning reserve services during evening hours due to high demand and the lack of available capacity to provide spinning reserve services.

(b) Keeping spinning reserves from conventional technologies in the absence of flexible technology is a more expensive option, as costlier plants need to be in operation.

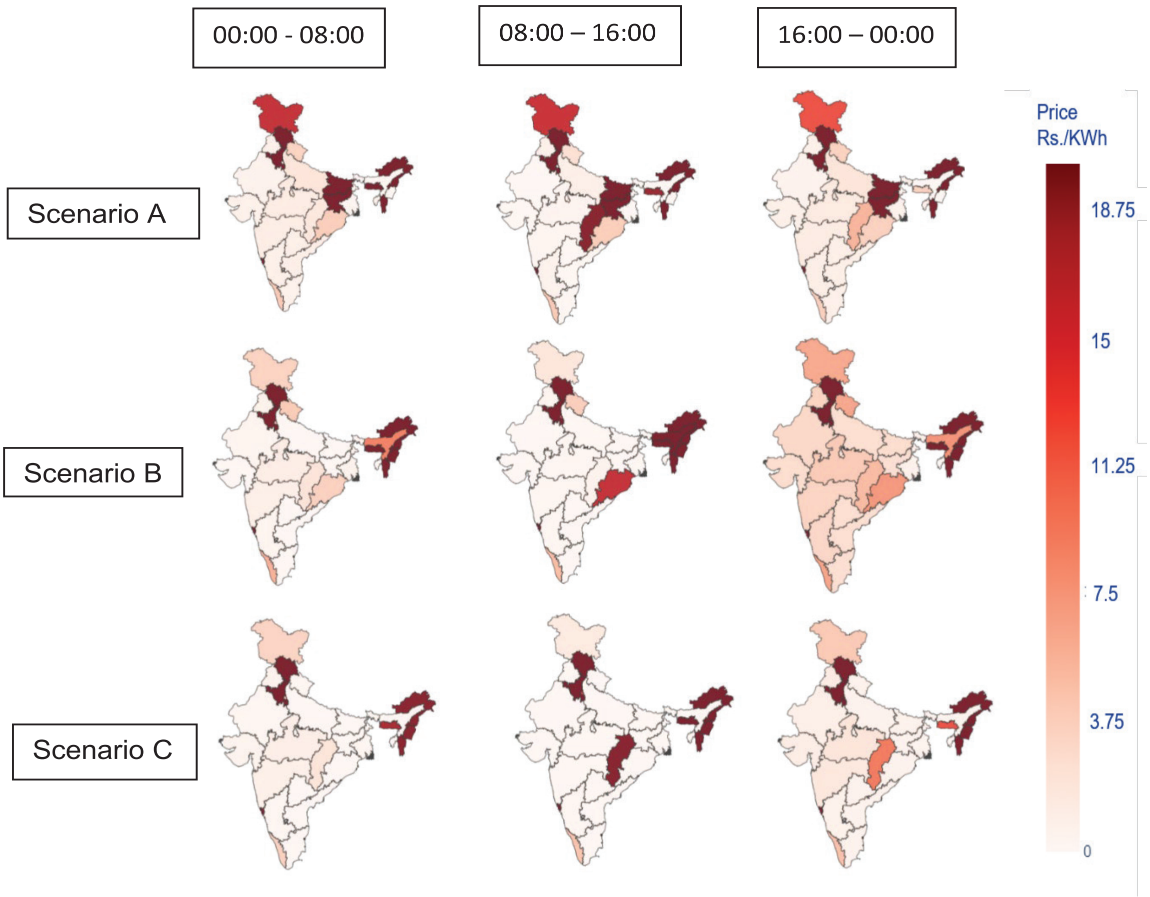


Figure 23: Spinning reserve prices for three different scenarios in the short-term markets are provided for three different periods of a day in the figures above. During evening hours, high spinning reserve prices are observed due to the high energy demand, and the plants are engaged to serve the energy need, leading to no (or less) free online capacity.

4.2.4. AS Prices for non-spinning services in a co-optimised energy and AS market

The non-spinning reserve is provided by the plants that are offline but can come online within 15 minutes. Hydropower and gas-fired plants are suitable for such requirements. A similar trend is also observed in CAISO [1]. The traditional gas-fired plants in India are fairly old and inefficient, so the gas turbine plants are not suited to providing such requirements. Moreover, operators do not want to cycle these plants more than once a day.

(a) In Bihar, Jharkhand, Gujarat, Haryana and Rajasthan, there is a significant demand for non-spinning reserve services.

(b) There is also a significant demand for non-spinning reserve services in all of India's northeast states.

(c) The demand for non-spinning reserves is mostly stable throughout the day due to the lack of offline flexibility technology.

(d) Scenario C (even with the presence of flexible technology) shows that there is a significant need for flexible resources to provide non-spinning reserve services in Maharashtra, Gujarat, Madhya Pradesh, Haryana, Himachal Pradesh, Bihar and Jharkhand.

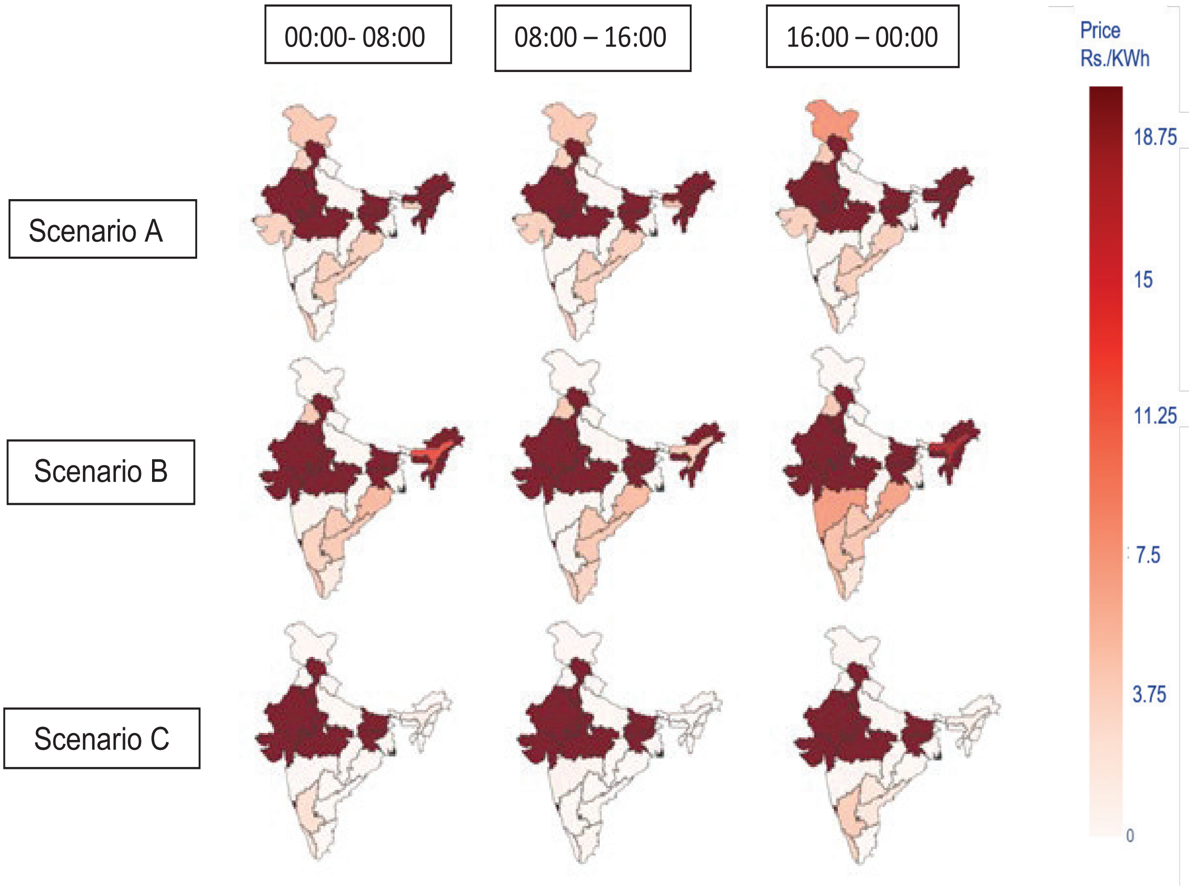


Figure 24: Non-spinning reserve prices for three different scenarios in the short-term markets are provided for three different periods of a day in the figures above. Due to the unavailability of flexible offline capacity, prices for non-spinning reserves are high.

The revenue earned by flexible technology will increase with the RE penetration across different US markets. On the other hand, the revenue earned by inflexible baseload resources will decrease [9, 11, 12, 13, 14]. From the previous years' data from four ISOs (CAISO, ERCOT, PJM and ISONE), it is evident that **BESS has the highest potential for revenue** as it can provide AS at any hour. The turbines and ICE can only provide regulation and spinning reserve services when they are online. However, due to the higher flexibility of ICE, **it has a greater scope for revenue than turbines.** The simulation results provided in this study also lead to similar conclusions.

CONCLUSION

(a) India needs AS and balancing capacities (at least 9 GW of ICE and 38 GW of BESS) by 2030.

(b) In the initial years, even when national markets are not established, the states need ICE and BESS capacities to better integrate RE capacities, reduce their operational costs and manage area control error better.

(c) After 2025–2026, when national markets are expected to be established, these capacities will seamlessly provide services required by the national power system.

(d) All this will be enabled by opening up capacity markets and expanding the scope of energy and AS markets – regulatory processes which have already commenced.

(e) If these markets were established today, the savings in operational costs would pay off the capital costs and the market prices for reserve services would be such that investments would come in.

(f) Coal and gas prices are expected to determine the marginal prices in the MBED framework. The impact of fuel price volatility (which is also currently being observed) can be smoothened with BESS and ICE-based reserves in the system.

(g) The intermittency of renewables in weather-dependent power systems is likely to accentuate market price volatility. BESS and other storage systems are seen to provide an effective cushion.

(h) TThe simulation results demonstrate that he prices for various types of ancillary services (energy and alternative AS) in India follow similar pattern as have been being observed in various US ISOs.

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