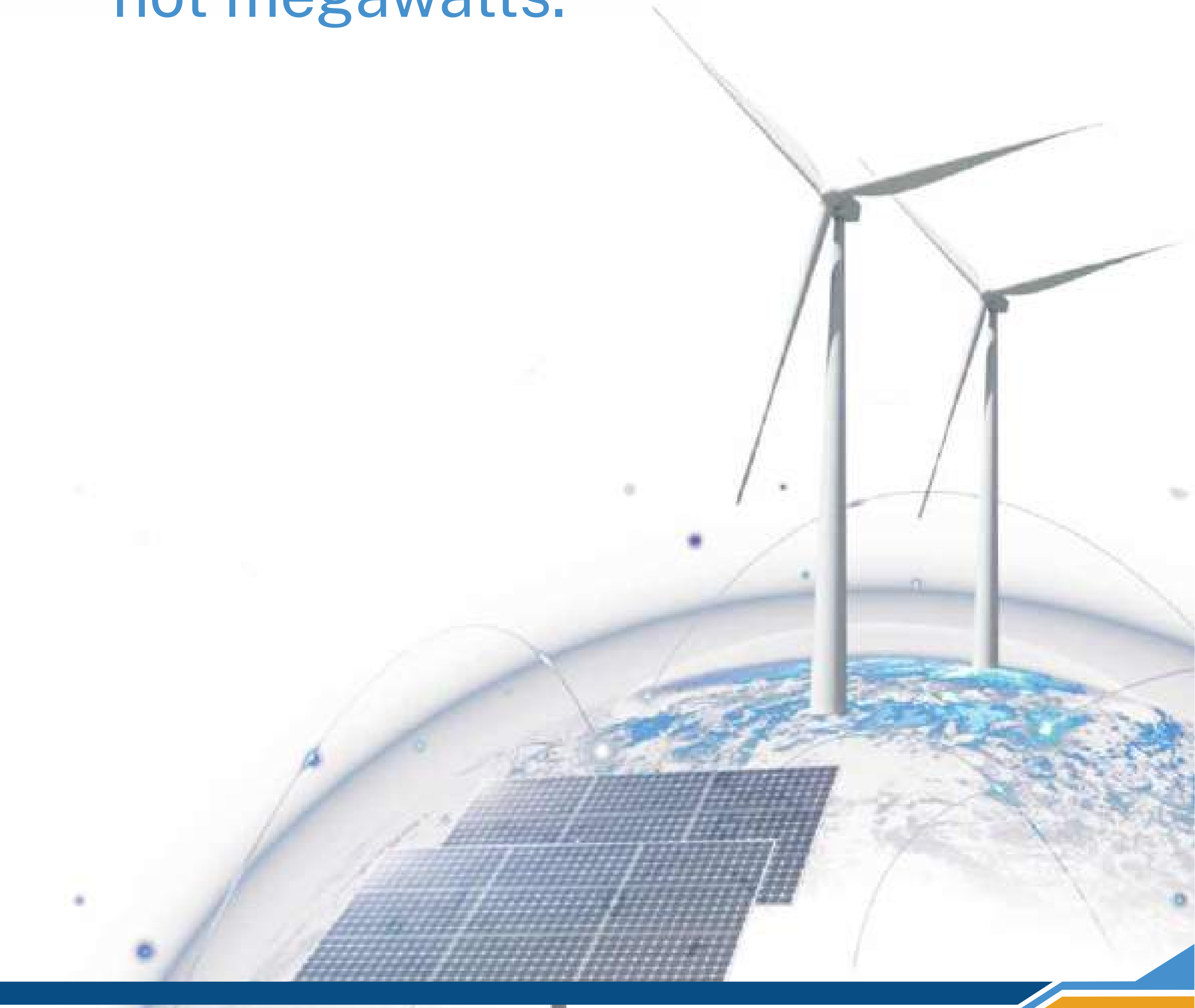
KIRTANE & PANDIT

Powering India's Growth

The Shift from Renewable Capacity to Reliable Energy

January 2026

India’s next energy chapter will be written in reliability, not megawatts.



Contents

1. Executive Summary

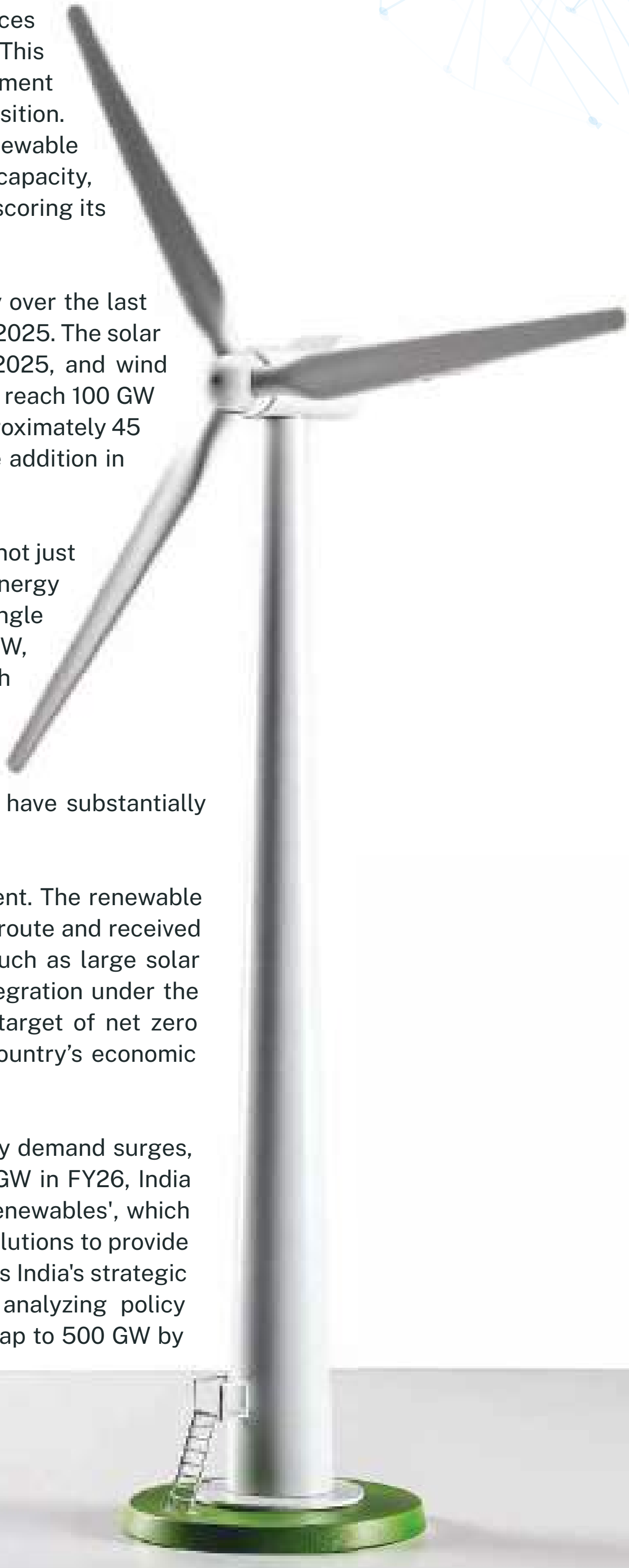
India's energy sector achieved a watershed moment in September 2025 when total installed capacity crossed 500 GW, with non-fossil fuel sources accounting for 51% (256 GW) for the first time in the nation's history. This milestone was achieved five years ahead of the 2030 Paris Agreement commitment, positioning India as a global leader in clean energy transition. According to The International Renewable Energy Agency (IRENA) Renewable Energy Statistics 2025, India ranks third globally in solar power installed capacity, fourth in wind power, and fourth in total renewable energy capacity, underscoring its emergence as a global renewable energy leader.

This progress is a result of a threefold increase in non-fossil fuel capacity over the last decade, from 81 GW in the pre-2014 period to nearly 250 GW by the end of 2025. The solar capacity has grown from 2.82 GW in 2014 to over 123 GW by August 2025, and wind capacity has expanded from 21 GW to over 52 GW, with a clear roadmap to reach 100 GW by 2030. India recorded unprecedented capacity addition in 2025, with approximately 45 GW of renewable capacity installed by November 2025, nearly double the addition in the same period of 2024.

Renewables are increasingly becoming a part of the electricity supply, and not just capacity. On July 29, 2025, India achieved a historic first: renewable energy sources met 51.5% of the nation's total electricity demand of 203 GW in a single day. This landmark event — with solar contributing 44.5 GW, wind 29.9 GW, and hydro 30.3 GW — demonstrated that India's grid can reliably operate with a majority of renewable power. The total generation of renewable electricity has increased by more than 100% in the last decade and stands at over 403 billion units in FY25. Renewable energy sources now contribute nearly 28% to total power generation, while power shortages have substantially reduced.

This transition has been facilitated by strong policy support and investment. The renewable energy sector allows 100% foreign direct investment under the automatic route and received around US$ 23 billion between April 2020 and March 2025. Schemes such as large solar parks, PM Surya Ghar Muft Bijli Yojana, SATAT and renewable energy integration under the Smart Cities Mission have increased access to clean energy, while the target of net zero emissions by 2070 has further solidified the role of renewables in the country's economic growth, employment, and energy security.

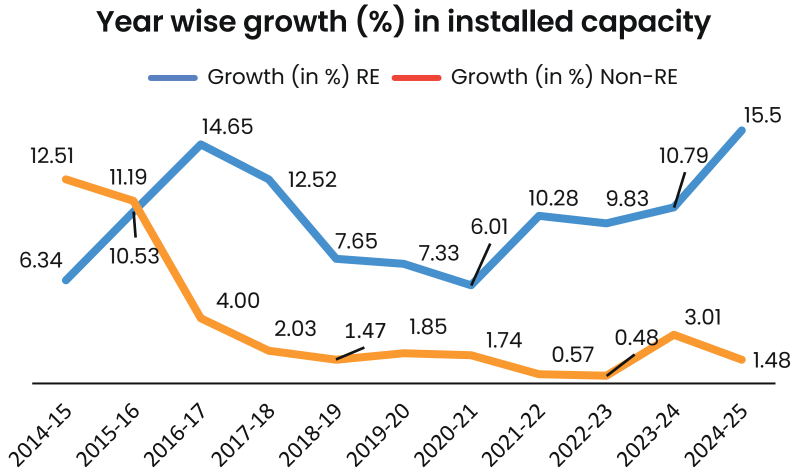
Yet this achievement marks not an endpoint, but a transition. As electricity demand surges, reaching 1,694 billion units in FY25 with projected peak demand of 277 GW in FY26, India must evolve from capacity addition to what can be termed as 'Reliable Renewables', which will integrate storage, transmission, hybrid, and smart grid management solutions to provide affordable, reliable, and round-the-clock clean energy. This report examines India's strategic transition from capacity-focused expansion to system-level reliability, analyzing policy frameworks, technology pathways, investment landscapes, and the roadmap to 500 GW by 2030.



2. India's Renewable Energy Landscape: From Capacity Leader to Reliability Imperative

2.1 India's current position in the renewables sector

Over the past decade, India has expanded its non-fossil fuel installed capacity from 81 GW before 2014 to approximately 250 GW by September 2025, representing a threefold increase. This growth has positioned India as the fourth-largest country globally in renewable energy installed capacity, fourth in wind power, and third in solar power. Solar energy has been the standout performer, recording a 42-fold increase from 2.82 GW in 2014 to over 123 GW by August 2025, supported by large-scale deployments, declining costs, and international initiatives such as the International Solar Alliance, which India co-founded to promote global solar cooperation across more than 120 countries.



Source: Ministry of New & Renewable Energy, Government of India

Wind energy has also seen steady expansion, growing from 21 GW in 2014 to 52.68 GW by August 2025, with a clear pathway toward 100 GW by 2030, particularly across wind-rich states such as Gujarat, Tamil Nadu, Karnataka, Maharashtra, Andhra Pradesh, and Rajasthan. Together with biomass, small hydropower, waste-to-energy, and large hydro projects, renewables now form the backbone of India's long-term energy strategy.

This expansion has been reinforced by strong policy support and investment momentum. The renewable energy sector allows 100% foreign direct investment under the automatic route and has attracted approximately US$ 23 billion in FDI between April 2020 and March 2025, reflecting sustained global investor confidence. India's commitment to achieving net-zero emissions by 2070, announced at UNFCCC Conference of the Parties (COP26), has further strengthened the role of renewables as a catalyst not only for decarbonisation, but also for industrial growth, employment generation, and energy security.

Government flagship programmes have played a critical role in accelerating adoption. Initiatives such as large solar parks, the PM Surya Ghar: Muft Bijli Yojana targeting one crore rooftop solar households, the SATAT programme for compressed bio-gas, and renewable mandates under the Smart Cities Mission are expanding clean energy access across urban and rural India. In 2025, India recorded its highest-ever six-month renewable capacity addition, installing 22 GW in the first half of the year.

At the same time, India's power demand continues to rise rapidly, driven by population growth, urbanisation, industrialisation, and increasing per-capita consumption. Electricity consumption rose to 1,694 billion units in FY25, a 33% increase over FY21, while peak power demand is expected to reach 277 GW in FY26. India is now the third-largest producer and consumer of electricity globally. While India's total installed electricity generation capacity reached 500.89 GW by the end of September 2025, by October 31, 2025, total capacity had further increased to 509.64 GW, reflecting the accelerating pace of clean energy deployment. This demand growth highlights the importance of not just adding renewable capacity but ensuring reliability, grid stability, and round-the-clock clean power through storage, transmission upgrades, and hybrid energy systems.

Renewable generation has grown in parallel, increasing from 190.96 billion units in FY15 to over 403 billion units in FY25, while the share of renewables in electricity generation has risen from 6% in FY15 to nearly 28% by 2025. Power shortages have declined sharply, underscoring improvements in supply adequacy and system planning, even as thermal power continues to play a stabilising role in meeting base-load requirements during the transition.

Looking ahead, the scale of opportunity is immense. Estimates suggest an investment potential of Rs. 40 lakh crore (US$ 462 billion) in the power sector over the next decade, driven by renewable energy expansion, grid modernisation, energy storage, and transmission infrastructure. The government's long-term infrastructure plan aims to meet a projected 458 GW demand by 2032, strengthen the national grid, and enhance energy security, while supporting India's ambition of 500 GW of non-fossil fuel capacity by 2030.

Reliable renewable energy resources provide uninterrupted, firm, dispatchable forms of clean energy with the integration of generation, storage systems, and smart grid management solutions. The goal is to move from intermittent energy sources towards reliable energy sources for delivering energy access at scale. In this context, India's renewable energy transition is no longer solely about capacity addition. The next phase, Reliable Renewables, centres on delivering affordable, resilient, and round-the-clock clean power that can sustain high economic growth, support inclusive development, and reinforce India's leadership in the global clean energy transition.

2.2 Beyond Megawatts - The Reliability Challenge in High-Renewable Systems

India's remarkable success in scaling renewable capacity, growing from 81 GW to over 250 GW in a decade, now requires a strategic evolution. While capacity addition remains important, ensuring system reliability, flexibility, and round-the-clock clean power delivery has become equally critical. International experience demonstrates that high renewable penetration without adequate attention to storage, grid infrastructure, and institutional frameworks can result in curtailment, reliability challenges, and suboptimal asset utilization.

○ Technical & System Limitations

• Flexibility and reliability gaps

Capacity-focused plans disregard the ramping, reserves, minimum up and down times, and variability in Variable Renewable Energy's chronology, which tends to underestimate flexibility requirements, particularly for unmet demand or extreme curtails at a large VRE penetration level. Variable renewables have low capacity credit (often 8–28% at ~10% penetration). This means that installed capacity does not add up to reliable capacity.

• Storage and grid under-provision

When storage is not co-optimized endogenously, the models underestimate its value and overbuild generation capacity at the expense of storage. Neglecting the network bottlenecks or low resolution causes sub-optimal locations and underestimation of the needs of the grid, while improving the network resolution can raise the system cost by as much as 23%.

These technical and system limitations manifest across multiple dimensions of power system planning and operation. International experience from markets with high renewable penetration — including California, Germany, Texas, and Australia — demonstrates that capacity-centric planning creates predictable challenges that must be addressed through integrated system design. Below Table summarizes how the focus on megawatt targets, without corresponding attention to flexibility and grid infrastructure, translates into operational and economic risks that can undermine the clean energy transition.

○ Key System-Level Issues

Limitation type	Manifestation in capacity-centric expansion
Variability & uncertainty	Curtailment, unmet demand, need for backup
Grid constraints	Hidden congestion, mis-siting, cost underestimation
Storage representation	Mis-valued storage, wrong mix of short/long duration
Temporal resolution	Time slice models overbuild certain VRE (e.g., solar) and mis-estimate gas/backup needs

Purely capacity-centric renewables expansion, chasing after MW targets without co-optimisation of flexibility, storage, grids, temporal/spatial detail, and institutional capacity, has the risk of high curtailment, reliability issues, and escalating costs rather than efficient deep decarbonization.

2.3 Towards firm and flexible clean power

Clean power transitions now focus not just on adding renewables, but on making systems firm (reliable at all times) and flexible (able to handle variability from wind/solar) across whole economies.

Analyses on global and regional routes reveal that 100% renewables are technically and financially viable in mid-century with solar and wind technologies as core technologies and a high degree of electrification/Power-to-X in the fuel and heat sectors. Such routes can rapidly abate CO_2 to near-zero levels by mid-century compared with a fossil system and at a decreased cost compared with a 100% renewable system because of system synergies and efficiencies discovered in a global route analysis. Renewables can supply around ⅔ of global primary and most electricity in 2050.

○ Key flexibility resources and strategies

Flexibility lever	Role in firm clean power
Storage (batteries, seasonal fuels, hydro)	Short-and long-duration balancing, capacity adequacy
Demand response & sector coupling	Shift loads (EVs, heat pumps, industry), add system-wide flexibility
Grid expansion & interconnection	Smooth variability across regions; enable high VRE shares
Flexible low-carbon generation	Hydro, bioenergy, gas with green fuels for rare scarcity periods

3. Policy Evolution: From Capacity Targets to System Reliability

The modern Indian strategy on reliable renewable energy cannot be appreciated without understanding it against the backdrop of historical trends in renewable energy policy that have been mostly capacity-focused for the last decade or so. The initial set of policies focused on scaling up renewable capacity to address energy deficits, reduce oil imports, and fulfil commitments on climate change. Succeeding in increasing capacity, it has become entrenched through current efforts to address stresses on renewable energy.

3.1 Historical Emphasis on Capacity Expansion

The policy structure for renewables developed in the advanced 2000s and 2010s dates back to the use of megawatt-based targets and incentives. The flagship programs, such as the Jawaharlal Nehru National Solar Mission (JNNSM), introduced in 2010, and the amendments to national-level targets for solar and wind power have been effective steps towards achieving the target of enhancing the pace of deploying these power generations through the use of feed-in costs, reverse auctions, or power purchase contracts.

However, the level of enhancement that was carried out during the period assumed that grid integration would take place through the use of available flexibility that could be attained. Such assumptions avoided the concerns that storage and ancillary services would have at the level that they could provide flexibility. At some point, the limitations that existed started manifesting themselves with the rising levels of renewable energy use within the system, particularly within the states that had an ample supply of sunlight.

By the late 2010s, policy discourse began shifting from pure capacity addition toward grid integration and system reliability. Key developments included the expansion of inter-state transmission planning for renewable energy zones, the introduction of forecasting and scheduling regulations for wind and solar, and early discussions around ancillary services markets. During this period, energy storage entered the policy conversation primarily as a supporting technology, rather than a core system asset. Pilot tenders for battery storage, pumped hydro recognition as renewable-enabling infrastructure, and initial viability gap funding discussions marked the beginning of a gradual reorientation. Nevertheless, storage deployment remained limited, constrained by high costs, regulatory ambiguity, and the absence of dedicated revenue mechanisms.

3.2 From Capacity to building Reliability

Against this historical backdrop, the budgetary approach represents a continuation and partial consolidation of India's shift toward system-level thinking. Rather than introducing a single transformative instrument, the budget builds incrementally on existing reforms to strengthen the commercial and institutional foundations for reliable renewables.

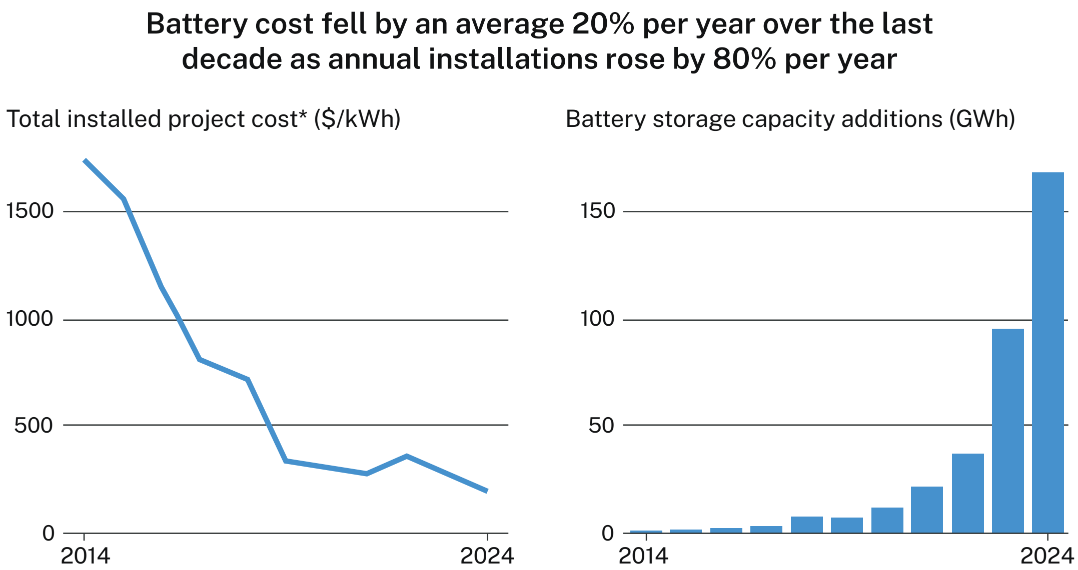
• **Strengthening Battery Energy Storage Systems**

Further reaffirming the focus of the People of India in the form of the country's Union Budget of 2025-26, in light of concurrent sectoral power sector reforms, is the strengthening notion of the importance of energy storage in relation to the continued expansion of renewable energy assurance. Union Budget 2025-26 allocated Rs. 25,649 crore (US$ 3.03 billion) to the Ministry of New and Renewable Energy, representing a 39% increase over the previous year's Rs. 19,100 crore. While this demonstrates growing commitment to the renewable sector, the budget focused on framework-driven rather than fiscally-driven storage support. Although the budget failed to appropriately introduce an umbrella of unified incentivizing mechanisms in the form of the best international standards, various policies are being established in the form of strengthening the business case of Battery Energy Storage Systems (BESS) itself.

These will include the continued use of Viability Gap Funding Mechanism for grid-scale storage development, expected to tackle issues such as the high capital expenditure for these projects and enhance their deployment. On the other hand, aspects such as the waiver of interstate transmission charge for storage-based renewable energy generation and the introduction of Energy Storage Obligations for distribution companies will play a significant role in ensuring the demand for energy storage is met, and this will also align energy storage deployment to the manufacturing requirements for indigenous energy management systems.

However, such measures notwithstanding, India's storage policy ecosystem still remains largely "framework-driven," as opposed to "fiscally-driven."

- **Rise of annual installations and fall of battery cost.**



Source:- The International Renewable Energy Agency (IRENA)

• Solar Storage Integration

Solar storage integration has emerged as a central feature of India's renewable procurement strategy. Recent tender designs and grid interconnection regulations increasingly allow for co-located or standalone storage, enabling renewable generators to offer more predictable and dispatchable power. Hybrid solar-plus-storage projects are now being positioned not merely as capacity additions, but as tools for managing variability, peak demand, and curtailment risks.

Under Budget 2025-26, this approach aligns with broader power sector goals of improving round-the-clock (RTC) renewable supply, reducing dependence on thermal peaking capacity, and supporting distribution companies in meeting reliability obligations. The growing emphasis on integrated projects reflects a policy shift away from capacity-centric targets toward system-level reliability and flexibility, a core theme of India's next phase of renewable energy transition.

• Grid-Scale Flexibility Mechanisms

Beyond generation and storage, Budget 2025-26 reinforces the importance of grid-scale flexibility through institutional and market reforms. The gradual operationalisation of ancillary services markets, proposed revisions to storage tariff frameworks, and continued investments in transmission infrastructure collectively aim to enhance the grid's ability to absorb high shares of variable renewable energy.

Energy Storage Obligations, though still evolving, represent an early attempt to internalise flexibility requirements within power procurement. However, challenges remain in defining storage as a distinct asset class within regulatory and tariff structures, particularly across state jurisdictions. Addressing these challenges will be essential to unlock private investment and ensure efficient utilisation of storage and other flexibility resources.

3.3 At a global level: Lessons from the USA and the EU

• United States: Inflation Reduction Act (IRA)

The United States' Inflation Reduction Act (IRA) represents a globally significant benchmark for clean energy policy, particularly in its treatment of energy storage. For the first time, the IRA extends Investment Tax Credit (ITC) eligibility to standalone storage systems, offering a base credit of up to 30 percent of project costs, with additional bonuses linked to domestic content, labour standards, and location.

Crucially, the IRA combines deployment incentives with manufacturing support, through production tax credits and direct-pay mechanisms that lower entry barriers for new investors. This integrated approach has substantially reduced investment risk, accelerated storage deployment, and strengthened domestic battery manufacturing supply chains. Compared to India's approach, the IRA provides greater fiscal certainty and long-term visibility for both developers and manufacturers.

• European Union: Net Zero Industry Act (NZIA)

The European Union's Net Zero Industry Act (NZIA) adopts a structurally different approach, focusing less on direct fiscal subsidies and more on industrial policy and regulatory streamlining. Batteries and storage technologies are designated as "net-zero strategic technologies," enabling priority permitting, reduced administrative timelines, and coordinated regulatory oversight.

The NZIA also introduces non-price criteria in public procurement and project evaluation, emphasising sustainability, resilience, and supply-chain security. While financial incentives are often channelled through complementary EU or member-state funding instruments, the NZIA's primary contribution lies in reducing regulatory uncertainty and accelerating project execution, particularly for clean technology manufacturing.

While the US and EU approaches offer valuable lessons, India's context differs significantly. With faster demand growth, lower per-capita income, and greater fiscal constraints, India's policy framework must balance ambition with affordability. The question for India is not whether to adopt US-style tax credits or EU-style regulatory streamlining, but how to craft a hybrid approach that mobilizes private capital while maintaining energy access and affordability.

3.4 Regulatory Gaps and Enabling Reforms in India

Despite progress in developing its Energy Storage System flexibility framework, it has several critical structural issues to be addressed, which relate to the absence of fiscal incentives similar to its Investment Tax Credit (ITC)-based program in the United States, issues arising due to incoherent tariff systems, financing risk, and dynamic grid integration, which contribute to increasing the overall risk with regard to increasing its costs of capital, especially in relation to its ability to deliver grid stability as provided by storage systems.

These challenges will need to be addressed through a coordinated reform agenda that includes targeted fiscal incentives in the form of investment-linked tax credits and accelerated depreciation, standardized national tariff and market structures that recognize storage as both an energy and ancillary services provider, and stronger integration with domestic manufacturing support under production-linked incentive schemes. By contrast with the fiscally expansive US model and the regulatory-streamlining approach of the European Union, India's Budget 2025-26 reflects a measured, incremental approach driven principally by policy signals and targeted support. This has facilitated some early momentum, but truly reliable, round-the-clock renewable power at scale will require deeper fiscal backing, clearer regulation, and market design reforms, particularly as India moves toward its 500 GW non-fossil capacity target and growing electricity demand.

4. Technology Pathways for Reliable Renewables

As India targets 500 GW of non-fossil fuel capacity by 2030 and aims for net-zero by 2070, the focus is shifting from standalone renewable projects to integrated solutions that ensure 24×7 supply. This requires a technology portfolio spanning battery storage, hybrid generation, long-duration storage, and AI-driven grid management — each playing a distinct role in India's reliable renewables strategy.

4.1 Battery Energy Storage Systems (BESS)

Battery energy storage is currently the most mature and widely deployed flexibility option for short- to medium-duration needs (from minutes to ~4–6 hours).

• Li-ion and LFP batteries

Lithium-ion (Li-ion), particularly lithium iron phosphate (LFP), dominates new utility-scale and behind-the-meter projects because of high round-trip efficiency (typically 85–92%), fast response (milliseconds), modularity, and rapidly declining costs. Global BESS costs have fallen by ~80–85% over the past decade, driven by scale in the EV sector and manufacturing learning curves.

In India, BESS is being integrated into solar and wind parks and tendered explicitly through standalone and "solar + storage" auctions by SECI, NTPC, and state utilities. The National Electricity Plan and recent announcements emphasise storage as a key enabler of 500 GW non-fossil capacity targets by 2030. BESS projects in India are increasingly designed to provide multiple services like energy shifting, peak shaving, frequency regulation, and contingency reserves that improve overall project economics.

India's battery storage market is experiencing rapid growth, driven by renewable integration needs, electric vehicle adoption, and grid modernization. The lithium-ion battery market, which forms the backbone of short-duration storage solutions, is projected to expand significantly over the next decade as costs decline and deployment scales up.

• Sodium-ion and alternative chemistries

Sodium-ion batteries are emerging as a promising alternative due to the abundance and lower cost of sodium, potential compatibility with existing Li-ion manufacturing lines, and better performance at higher temperatures, which is an advantage in Indian conditions. While energy density is lower than Li-ion, they may be attractive for stationary storage where volume and weight are less critical and cost and sustainability are more important.

• Flow batteries and long-duration storage

- Smoother output and reduced ramping requirements for conventional plants
- Better alignment with demand profiles, particularly in evening peaks

When integrated with BESS, hybrids can deliver partially dispatchable profiles, for example, committing to a firm output during specific time blocks. Early Indian hybrid + storage tenders have demonstrated that blended tariffs can remain competitive with new coal under certain configurations, particularly when policy and concessional financing reduce capital costs.

4.2 Round-the-Clock (RTC) and Firm Renewable Power Contracts

Round-the-clock and “firm, dispatchable renewables” contracts are a key market mechanism linking technology pathways to system reliability outcomes. Under RTC tenders, developers must meet a specified availability (e.g., 80–90%) across the day and year, often with penalties for shortfalls. This compels portfolios that combine geographically diversified solar and wind, storage, and sometimes limited thermal backup to ensure firm supply.

In India, SECI’s RTC tenders have shown that developers can structure portfolios that deliver high renewable content while maintaining grid-relevant reliability metrics. These contracts are particularly attractive for:

- DISCOMs seeking to meet Renewable Purchase Obligations (RPO) without compromising reliability
- Commercial and industrial (C&I) consumers requiring 24x7 green power for ESG and competitiveness reasons
- Public sector entities with long-term decarbonisation goals

Globally, similar constructs of “clean firm power” or firmed renewable PPAs are emerging in markets such as the US and Europe, often supported by storage and flexible demand. These models demonstrate that with appropriate risk allocation and performance incentives, technology portfolios can substitute for traditional baseload or mid-merit plants.

4.3 Emerging Technologies: Long-Duration Storage and AI-Driven Grid Management

• Long-duration energy storage (LDES)

For very high renewable shares, multi-day to seasonal flexibility becomes critical. A range of long-duration options is under development and demonstration:

- Pumped hydro storage (PHS): The most mature LDES, already deployed in India (e.g., Tehri PSP, Srisailam). New pumped storage projects are being prioritised in several states due to their large capacity, long lifetimes, and ability to provide a wide spectrum of grid services.
- Hydrogen and power-to-X: Renewable electricity can produce green hydrogen via electrolysers, which can be stored and later reconverted to power through fuel cells or gas turbines, or used directly in industry and transport. While round-trip efficiency is low compared to batteries, hydrogen offers very large-scale, long-duration storage potential.
- Thermal and mechanical storage: Technologies such as molten salt, liquid air energy storage, and advanced compressed-air storage are being piloted internationally to offer long discharge durations, often co-located with industrial or district heating applications.

For India, a portfolio combining BESS for short-term balancing, pumped hydro for diurnal/weekly balancing, and green hydrogen or other LDES for seasonal needs is likely to be more cost-effective than relying on a single technology.

• AI-driven and digital grid management

Advances in forecasting, optimisation, and control are increasingly as important as physical assets. Machine learning and AI are being applied to:

- Improve short-term solar and wind forecasts, reducing reserve requirements and curtailment
- Optimise dispatch of storage and flexible loads across multiple markets (energy, capacity, ancillary services)
- Enhance real-time congestion management and remedial action schemes
- Support predictive maintenance and asset health monitoring for both renewable plants and network infrastructure

For India's rapidly evolving grid with increasing distributed solar, electric vehicles, and demand-side flexibility, digital solutions and advanced metering will be essential to unlock the full value of storage and hybrid assets.

4.4 Implications for India's Reliable Renewable Strategy

Collectively, these technology pathways support a shift from a capacity-centric approach (MW installed) to a reliability-centric paradigm (MWh, ramping capability, and firm capacity). Key implications include:

- Planning: Integrated resource planning must account for storage duration, flexibility, and locational value, not just levelised cost of energy.
- Policy and regulation: Tariff structures, grid codes, and market rules need to recognise and remunerate flexibility and reliability services.
- Industry and investment: Project developers and manufacturers must align portfolios with emerging RTC, hybrid, and ancillary service markets and strengthen domestic supply chains for batteries and other critical technologies.

A balanced mix of mature (Li-ion, PHS, hybrids) and emerging (sodium-ion, flow batteries, hydrogen, AI- optimized systems) solutions will be crucial to deliver reliable, affordable, and clean power in line with India's 2030 and 2047 targets.

5. Manufacturing and Supply Chain Dynamics

As India's renewable energy market continues to expand into an accelerated deployment and system integration phase, market conditions appear to be dictated by two primary concerns: "scale and self-reliance." Rapid market development, accompanied by an increasingly charged energy security environment, geopolitical uncertainties, and strategic imperatives pertaining to industrial self-sufficiency, all appear to be resulting in an overarching trend, wherein manufacturing assumes an unprecedented prominence from an overarching policy framework, while simultaneously dictating policy prescriptions for several core energy segments that have lent unprecedented momentum to this development imperative: Batteries, Solar, Inverters, etc.

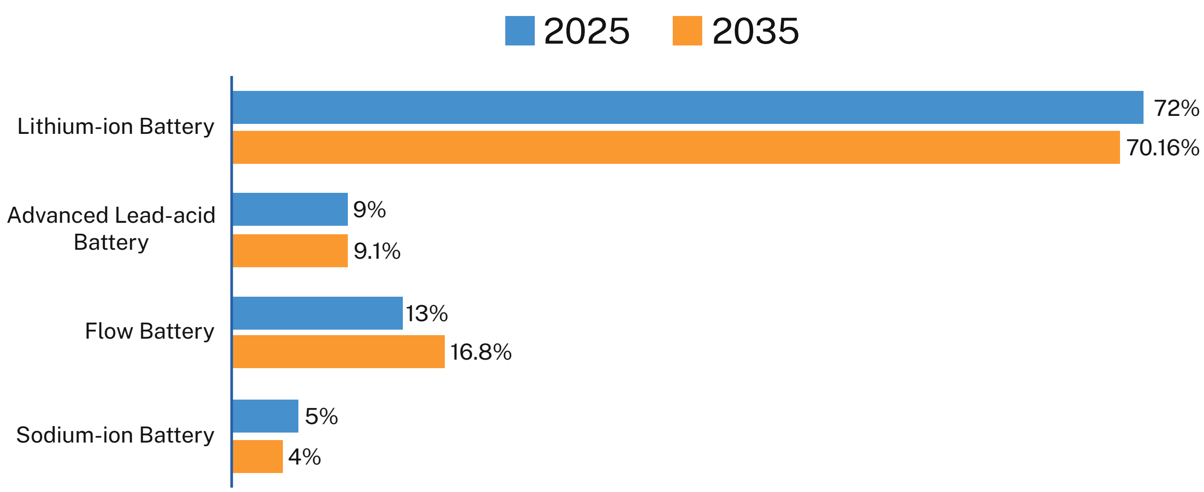
5.1 Domestic Manufacturing: Batteries and Components

- Global experience with EV battery reshoring shows that moving mid-/downstream manufacturing onshore can cut battery carbon footprint ~15% and energy use 5–7%, but upstream mining remains globally dispersed.

- Governments identify needs across the value chain: advanced cell manufacturing, component production, process innovation, and data-driven manufacturing optimization to meet surging demand and cost targets.

- Domestic circular-economy capabilities (refurbishment, recycling) can make locally made batteries more sustainable and cost-effective, as shown for lead-acid systems in South Africa.

India Battery Energy Storage System Market Share, by Battery Type, 2025 vs 2035 (%)



Source:- Acumen Research and Consulting

5.2 Domestic Manufacturing: Solar Modules and Inverters

India has achieved a manufacturing breakthrough in solar photovoltaics, with indigenous module manufacturing capacity under the Approved List of Models and Manufacturers (ALMM) reaching approximately 144 GW per annum by December 2025 - a nearly fourfold increase from 38 GW in March 2024. This includes approximately 81 GW of capacity added in calendar year 2025 alone, reflecting a 99% year-on-year increase. Additionally, solar cell manufacturing capacity has reached 24 GW under ALMM List-II, positioning India as a major global solar manufacturing hub.

Key instruments include ALMM, Basic Customs Duty, and especially PLI schemes, which are welcomed by firms but undermined by policy reversals, overlapping rules, and fragmented supply chains.

5.3 Production Linked Incentive Schemes and Localisation Efforts

PLI is a central tool to boost domestic manufacturing, reduce imports, and attract FDI, with large multi-sector outlays including renewables. Evidence highlights that PLI must be paired with ecosystem development (ancillaries, R&D, skills, logistics) and predictable policy to deliver durable competitiveness.

As of December 2025, the country's solar manufacturing capacity has risen to unprecedented heights, with module manufacturing capacity set to surpass 125 gigawatts (GW), a staggering 229% increase from the 38 GW registered in March 2024.

The performance parameters of the PLI scheme have clearly indicated its success in promoting manufacturing. As of June 30, 2025, the scheme has led to the creation of 18.5 GW of operational solar module manufacturing capacity, 9.7 GW of solar cell manufacturing capacity, and 2.2 GW of ingot-wafer manufacturing capacity. The government, aware of the difficulties being faced by the manufacturers in terms of equipment procurement, supply chain, and technology transfer, extended the commissioning dates by two years in September 2025.

India's battery storage market is expected to undergo significant technology diversification over the coming decade. While lithium-ion batteries currently dominate deployments, alternative chemistries, including sodium-ion and flow batteries, are projected to capture growing market share as they mature commercially and offer advantages for specific applications.

5.4 Supply Chain Risks and Mineral Dependencies

India's renewable energy manufacturing ambitions face strategic supply chain vulnerabilities, such as High dependence on lithium, cobalt, and rare earth elements, Geographic Concentration creating vulnerability to trade disruptions, Cost-Security Trade-off etc.

Risk Area	Key Issues
Mineral criticality	High reliance on lithium, cobalt, rare earths, tin with conflict, toxicity, and finite availability concerns
Geographic concentration	China dominates many PV, battery, and critical mineral value chains, creating vulnerability to trade/geopolitical shocks
Local vs global trade-off	Full localisation raises module costs; globalised PV supply cut prices by 20–25% vs domestic-only scenarios

Addressing these risks requires diversifying supplier relationships, building strategic mineral reserves, investing in domestic mineral exploration, and developing comprehensive recycling infrastructure to create circular supply chains.

6. Market Design and Business Models

6.1 RTC Tenders and Hybrid Auctions in India

India's renewable energy market design has progressively shifted from standalone, least-cost generation toward procurement mechanisms that emphasise reliability, firm supply, and system integration. This transition is most visible in the emergence of Round-the-Clock (RTC) renewable energy tenders and hybrid auctions, which combine solar, wind, and increasingly energy storage within a single contractual framework.

RTC tenders require developers to supply power continuously, typically ensuring 80–90% annual availability. By embedding intermittency management within project design, these tenders internalise balancing costs that were previously borne by the grid or thermal generators. Hybrid auctions-most commonly solar–wind and solar–storage configurations-leverage resource complementarity to smooth generation profiles, improve capacity utilisation, and reduce curtailment risks.

Together, these instruments mark a shift from capacity addition as a policy objective to performance-based procurement, aligned with grid reliability and demand patterns. However, RTC and hybrid tenders also introduce higher technical, financial, and operational complexity, particularly in the absence of mature flexibility and ancillary services markets to provide additional revenue certainty.

6.2 Role of DISCOMs, C&I Consumers, and Open Access Markets

Distribution companies (DISCOMs) remain central actors in India's renewable energy transition, as primary buyers of power and custodians of demand forecasting and grid stability. Their procurement choices, financial health, and contracting practices significantly influence the adoption of RTC and hybrid renewable models. While long-term power purchase agreements (PPAs) continue to dominate utility-scale renewables, concerns around payment delays and tariff rigidity have prompted developers to explore alternative offtake arrangements.

In this context, commercial and industrial (C&I) consumers have emerged as a critical source of demand for reliable renewable power. Motivated by rising electricity costs, decarbonisation commitments, and energy security considerations, C&I consumers increasingly procure renewable energy through open access, group captive structures, and corporate PPAs. For this segment, storage-backed and hybrid renewable solutions offer greater value by enabling peak load management, improved supply reliability, and partial insulation from grid volatility.

Open access markets thus play an important role in enabling innovative business models for reliable renewables. However, their growth is constrained by regulatory barriers, including cross-subsidy surcharges, banking restrictions, and policy uncertainty across states. Addressing these challenges is essential to scale private-sector participation in firm renewable power markets.

6.3 Revenue Stacking and Ancillary Services Markets

The economic viability of storage-enabled renewable projects increasingly depends on revenue stacking, whereby assets earn income from multiple value streams beyond energy sales. These include time-shifted energy arbitrage, capacity support, frequency regulation, ramping services, and other ancillary functions critical to grid stability.

India has taken initial steps toward developing ancillary services markets, with regulatory frameworks and pilot mechanisms aimed at enabling market-based procurement of flexibility services. However, these markets remain at an early stage, characterised by limited participation, shallow price discovery, and unclear long-term remuneration structures. As a result, most storage and hybrid projects currently rely on contracted revenues under PPAs or government-supported tenders, rather than fully market-driven flexibility payments.

The absence of mature ancillary and capacity markets constrains innovation in storage business models and limits the system-level value that flexible assets can capture. International experience suggests that well-defined flexibility markets are crucial for transforming storage from a cost add-on into a revenue-generating grid asset. For India, accelerating the development of such markets will be critical to supporting high renewable penetration while maintaining system reliability.

6.4 Investment Landscape and Cost Trends

The rapid scale-up of renewable energy in India has been accompanied by evolving cost structures, particularly with the increasing integration of energy storage into generation projects. Historically, declining capital costs in solar and wind power were the primary drivers of renewable adoption. However, as the focus shifts toward dispatchable and round-the-clock renewable energy, storage has emerged as a significant component of overall project capital expenditure (CAPEX).

Battery Energy Storage Systems (BESS) substantially increase upfront costs in solar- and hybrid-based projects, with CAPEX dominated by battery cells, power electronics, and balance-of-system components. While global lithium-ion battery prices have declined sharply over the past decade, recent volatility in critical mineral prices has introduced short-term cost uncertainty. Nevertheless, medium- to long-term projections indicate continued cost reductions driven by economies of scale, technological improvements, and expanding domestic manufacturing under production-linked incentive frameworks.

Operating expenditure (OPEX) profiles for storage-integrated projects differ markedly from conventional renewable assets. In addition to routine operations and maintenance, storage systems entail costs related to battery degradation, replacement cycles, thermal management, and software-based energy management systems. Over project lifetimes, these factors influence levelised cost calculations and necessitate more sophisticated asset management strategies. Despite higher OPEX, storage-enabled projects deliver system-level benefits such as reduced curtailment, peak-shifting, and improved capacity utilisation that can offset costs when appropriately valued within market and regulatory frameworks.

- **Some practical examples are as follows:**

1. Kajra Solar + BESS Project (Bihar)
The Bihar State Power Generation Company has commissioned the first phase of the 301 MW solar-plus-495 MWh BESS project at Kajra in Lakhisarai district, constructed at an estimated cost of ~₹1,810 crore for 185 MW/254 MWh and ~₹1,055 crore for the 116 MW/241 MWh second phase.

2. Standalone BESS Tender (West Bengal)
West Bengal State Electricity Distribution Company (WBSEDCL) invited bids for a 250 MW /1,000 MWh standalone BESS at the Goaltore substation, with a greenshoe option for additional capacity, marking one of the largest utility-scale storage tenders in the state.

3. Telangana is emerging as a leader in India's energy storage and renewable energy transition. The Telangana Power Generation Corporation (TGGENCO) has recently issued tenders for large standalone BESS totalling 375 MW/1,500 MWh at strategic grid points such as Maheswaram and Chhoutuppal. These deployments are designed to enhance grid flexibility, manage peak demand and integrate variable renewables more effectively.

6.5 Financing Challenges and Risk Perception

Financing remains one of the most significant barriers to scaling storage-integrated renewable projects in India. Lenders and investors often perceive storage as a relatively new and higher-risk asset class, particularly in the absence of long operating histories, standardised performance benchmarks, and clearly defined revenue streams. This risk perception translates into a higher cost of capital, shorter loan tenors, and more conservative debt-equity structures compared to standalone solar or wind projects.

Key financing challenges include uncertainty around long-term tariffs, limited clarity on ancillary services remuneration, technology risk related to battery performance and degradation, and exposure to regulatory changes at the state level. Additionally, the financial health of distribution companies (DISCOMs) continues to influence credit risk assessments, especially for projects reliant on long-term power purchase agreements.

As a result, most storage deployments to date have been driven by government-supported tenders, viability gap funding mechanisms, or balance-sheet-backed developers with access to lower-cost capital. Unlocking large-scale private investment will require greater regulatory certainty, improved bankability of storage revenue models, and the development of secondary markets for flexibility services.

6.6 Role of Blended Finance and Multilateral Institutions

Blended finance is emerging as a key enabler for storage and hybrid renewable investments by de-risking early projects and crowding in private capital. By pairing concessional funds with commercial financing, these structures lower financing costs, extend tenors, and address risk perceptions that continue to deter lenders, especially for first-of-a-kind storage and flexibility assets.

Multilateral and climate finance institutions including the World Bank, ADB, AIIB, and the Green Climate Fund are playing a catalytic role in India through policy-based lending, credit enhancements, and risk-sharing facilities, alongside technical assistance and regulatory support that improve project bankability.

As India moves toward higher shares of variable renewables, scaled deployment of storage will depend on strategically deploying blended finance to mobilise private investment and align near-term projects with long-term system needs. A comparison with the US and EU shows convergence on storage as a system enabler, but divergence in policy design, risk allocation, and public support mechanisms, and these are factors that will ultimately determine the speed and scale of investment.

6.7 Comparative Investment Lens: India with the USA and the EU

• Operating Costs, Asset Lifetimes, and Performance Risk

OPEX considerations for storage-integrated projects such as battery degradation, replacement cycles, and software-driven asset management are common across jurisdictions. However, investor treatment of these costs differs significantly.

In India, limited operational track records and the absence of standardised performance benchmarks heighten perceived technology and degradation risks. These uncertainties are often priced into financing terms, increasing overall project costs. In the US and EU, longer operating histories, standardised warranties, and clearer performance guarantees have reduced perceived OPEX risk, improving lender confidence.

Moreover, mature data ecosystems and digital monitoring frameworks in the US and EU support more accurate lifecycle cost modelling, whereas in India such capabilities are still evolving, particularly for large-scale grid storage applications.

• Financing Environment and Risk Allocation

The most pronounced divergence across regions lies in financing conditions and risk allocation. In India, storage-integrated projects are commonly financed through government-backed tenders, viability gap funding, or corporate balance sheets. Commercial lenders remain cautious due to tariff uncertainty, regulatory variability across states, and limited visibility on non-energy revenue streams such as ancillary services.

By comparison, the US investment environment benefits from long-term federal tax incentives that directly lower revenue risk, enabling projects to secure longer-tenor debt at lower cost of capital. The ability to monetise multiple value streams like energy, capacity, and ancillary services within relatively mature markets further enhances bankability.

In the EU, while direct subsidies are more constrained, financing risk is mitigated through regulatory harmonisation, priority permitting for strategic technologies, and access to blended EU-level financing instruments. This framework reduces non-financial barriers to investment and supports capital mobilisation for both deployment and manufacturing.

• Implications for India's Investment Trajectory

This comparative lens suggests that India's storage investment model is currently more policy- and institution-dependent than those of the US and EU, reflecting its earlier stage of market development. While this approach has enabled initial deployment and learning, sustained scale-up will depend on gradually shifting from reliance on public and concessional finance toward market-driven investment supported by predictable revenue frameworks.

As India's renewable penetration deepens and storage becomes a system necessity rather than a policy experiment, convergence toward global best practices ,particularly in risk allocation, revenue certainty, and cost recovery will be critical. At the same time, India's unique demand growth trajectory and development priorities imply that its investment pathway will remain distinct, blending elements of state-led coordination with emerging market-based mechanisms.

7. Strategic Outlook and Industry Perspectives

7.1 Renewables Industry Challenges & Potential Risks

• Grid Readiness and Transmission Constraints

India's renewable capacity has grown faster than supporting transmission infrastructure, creating bottlenecks that constrain power evacuation and increase curtailment risk. Key challenges in this respect include -
Delayed Transmission Projects: Several critical Green Energy Corridor links remain under construction, delaying renewable power evacuation from high-generation states.

Inadequate Grid Flexibility: Most of India's grid infrastructure was designed for baseload thermal generation rather than variable renewable power, limiting real-time balancing capability.
Coordination Gaps: Asynchrony between generation planning and transmission planning sometimes results in stranded generation capacity.

Addressing these constraints requires accelerated transmission investment, faster project approvals, advanced forecasting and scheduling systems, and stronger coordination between central and state agencies.

• Cost Recovery and Tariff Design

Unsupportive tariff structures and revenue uncertainty remain at the core of challenges facing storage-backed and hybrid renewable projects. The prevailing energy-only tariff regime recognizes the flexibility, reliability, and system services provided by storage only to a limited extent, thereby severely limiting bankability outside specialized RTC and hybrid tenders. Financial stress among distribution companies further makes them shy away from procuring higher-cost but system-critical clean energy solutions. Lack of transparent market mechanisms for capacity payments, ancillary services, and time-of-day pricing dilutes commercial viability, placing storage as a cost burden rather than a grid asset. This calls for comprehensive tariff reform to unlock truly sustainable private investment and system efficiency gains. Enabling tariff reforms accordingly should include Time-of-Day Tariffs, Capacity Payments, Ancillary Services Markets and Multi-Year Tariff Frameworks.

• Technology Obsolescence and Recycling Concerns

The rapid pace of battery technology advancement creates both opportunities and risks for investors. While costs are declining and performance improving, early-stage deployments may face competitiveness challenges before the end of their operational life as newer, superior technologies emerge at lower costs. This technology obsolescence risk is particularly acute for utility-scale projects with 15-20 year operational horizons.

Simultaneously, India's growing battery deployment will generate significant end-of-life waste over the coming decades. With limited domestic recycling infrastructure and evolving regulatory frameworks, concerns around environmental compliance, disposal costs, and producer responsibility add uncertainty to long-term project economics.

7.2 India's Strategic Priorities

As renewable penetration deepens, India's energy strategy is shifting decisively from capacity addition to system reliability, flexibility, and resilience. Having scaled generation rapidly, the next phase focuses on delivering round-the-clock, affordable power amid rising demand and increasing variability. Energy storage is emerging as a core grid asset rather than a supplementary add-on, critical for managing intermittency, meeting peak demand, reducing curtailment, and limiting reliance on thermal peaking capacity. Government planning increasingly embeds storage alongside transmission expansion and digital grid management in future system design. Equally central is the modernisation of transmission and distribution infrastructure. Accelerated interstate transmission, grid automation, and improved forecasting and dispatch are essential to evacuate renewable power efficiently, reduce congestion, and maximise asset utilisation.

Market design is also evolving. With energy-only markets proving insufficient for high-renewable systems, policy attention is turning toward mechanisms that value flexibility, capacity adequacy, and ancillary services, enabling storage and hybrid resources to participate as bankable grid assets. In parallel, domestic manufacturing and supply-chain resilience are being treated as strategic priorities. Batteries, power electronics, and clean-energy equipment are increasingly viewed as critical infrastructure, with lifecycle considerations such as recycling gaining importance as deployment scales.

Overall, the transition is being framed not just as decarbonisation, but as a foundation for energy security, industrial growth, job creation, and long-term economic resilience, aligned with India's net-zero target for 2070.

7.3 Industry Action Points

Industry stakeholders, developers, utilities, financiers, and technology providers are expected to adapt their strategies in response to this evolving landscape. Developers are increasingly designing hybrid and portfolio-based projects that combine generation, storage, and flexible offtake arrangements to manage variability and revenue risk.

Distribution companies are gradually being positioned as system managers rather than passive power buyers, with greater responsibility for balancing cost, reliability, and long-term system adequacy. Commercial and industrial consumers are expected to play a growing role in shaping demand for reliable renewables, particularly through open access and corporate procurement models.

Financial institutions and investors are also adjusting to the transition, with growing interest in blended finance structures, long-term infrastructure capital, and risk-sharing mechanisms suited to storage-integrated projects. Technology providers are focusing on innovation in system integration, digital controls, and battery lifecycle management to align with emerging system needs.

7.4 Medium and Long-Term Outlook

By 2030, India is expected to have largely completed the transition from renewable energy as a marginal resource to renewables as the core of the power system, with storage and flexibility mechanisms playing a central role in ensuring reliability. The emphasis during this period is likely to be on operational excellence, grid stability, and market maturity, rather than rapid capacity growth alone.

Looking toward 2047, India's power sector is envisaged as the backbone of a low-carbon, high-growth economy. Reliable renewables, supported by large-scale storage, smart grids, diversified clean energy sources, and advanced market mechanisms, are expected to underpin electrification across transport, industry, and households. The strategic direction taken in the current decade will therefore be critical in shaping the sustainability, resilience, and competitiveness of India's energy system over the long term.

References/ Sources

- Central Electricity Authority, Government of India
- Ministry of New and Renewable Energy, Government of India
- Ministry of Power, Government of India
- Press Information Bureau (PIB), Government of India
- Union Budgets of the Government of India
- India Brand Equity Foundation (IBEF)
- International Renewable Energy Agency (IRENA)
- International Energy Agency (IEA)
- World Bank
- United States Congress. Inflation Reduction Act of 2022
- European Union - Net Zero Industry Act
- Grand View Research
- Acumen Research and Consulting
- Wright Research

KIRTANE & PANDIT

Pune

5th Floor, Wing A, Gopal House, S.No. 127/1B/ 11,
Plot A1, Kothrud,
Pune – 411 038, India
Contact no : +91 20 67295100 / 25433104
E -mail : kpca@kirtanepandit.com

Mumbai

601, 6th Floor, Earth Vintage, Senapati Bapat
Marg, Dadar West,
Mumbai- 400 028, India
Contact no : 022 69328846 / 47
E -mail : kpcamumbai@kirtanepandit.com

New Delhi

272, Rajdhani Enclave, Pitampura,
Delhi-110034, India
Contact no : +91-96438 74488
E -mail : kpcadelhi@kirtanepandit.com

Bengaluru

No. 63/1, I Floor, Makam Plaza, III Main Road,
18th Cross, Malleshwaram, Bengaluru – 560
055, India
Contact no : 080 23443548 / 23461455
E -mail : kpcabengaluru@kirtanepandit.com

Nashik

Gajra Chambers, Second Floor,
Kamod Nagar, Indira Nagar,
Nashik – 422009, India
Contact no. : +91 253-2386644
E - mail : kpcanashik@kirtanepandit.com

Hyderabad

401 to 405, 4th Floor, Sanatana Eternal,
3-6-108/1, Liberty Road, Himayatnagar,
Hyderabad - 500 029, India
Contact no : +91 99127 41089 / 94400 55917 /
98480 44743 / 98480 46106
E -mail : kpcahyderabad@kirtanepandit.com

Chennai

No. 128, Old No. 34, Unit No. 1, 6th Floor,
Crown Court, Cathedral Road Gopalapuram
Chennai 600086
Contact no : 044 47990259
E -mail : kpcachennai@kirtanepandit.com

Follow Us On:

kpca@kirtanepandit.com
www.kirtanepandit.com

Authored by

KP Knowledge Management Group