June 2025

Institute for Energy Economics and Financial Analysis

Battery Storage and the Future of Pakistan's Electricity Grid

Understanding the risks and solutions as solar and battery storage adoption accelerates

Haneea Isaad, Energy Finance Specialist, IEEFA

Syed Faizan Ali Shah, Guest Contributor/Co-author

Contents

Figures

Tables

Key Findings

Battery storage adoption is accelerating in Pakistan's residential, commercial, and industrial sectors, driven by high electricity costs and declining solar component prices. Consumers are combining solar with Battery Energy Storage Systems (BESS) to reduce grid dependence, lower energy bills, and improve reliability. This trend is expected to continue as battery economics improve.

Solar with BESS has a payback period of 3-5 years in Pakistan's residential sector despite a 48% cost increase from surcharges and duties on lithium-ion batteries. The payback period ranges between 4-6 years for the commercial and industrial sectors, depending on battery size or usage requirements.

Pakistan imported an estimated 1.25 gigawatt-hours (GWh) of BESS in 2024. This could increase to 8.75GWh, or 26% of the projected peak demand in 2030, if business as usual persists. Such a shift could lead to stranded peak generation assets and higher financial losses for the grid.

Unmanaged BESS growth could destabilize Pakistan's national grid by reducing demand and raising capacity payments. Timely investments in grid modernization, smart metering, and regulatory updates can enable decentralized solar plus BESS configurations, avoiding expensive generation expansion and supporting strategic power planning.

1. Executive Summary

The convergence of rising energy prices and falling costs for Distributed Energy Resources (DER), such as rooftop solar photovoltaic (PV) systems and Battery Energy Storage Systems (BESS), have encouraged consumers to adopt decentralized energy solutions, reducing reliance on the grid and energy costs.

Pakistan imported an estimated 1.25 gigawatt-hours (GWh) of lithium-ion battery packs in 2024 and another 400 megawatt-hours (MWh) in the first two months of 2025, a trend that is likely to continue. As BESS adoption accelerates, it has the potential to reshape Pakistan's energy landscape, driving the shift toward a more decentralized, consumer-centric system. While necessary, adding DERs to Pakistan's conventional grid presents multiple challenges.

The country's rapid adoption of solar PV systems has already started impacting centralized grid generation. As more consumers shift to net metering and self-generation, the overall electricity demand from the national grid has started declining. However, due to contractual obligations resulting from long-term power purchase agreements, the exit of paying consumers from the grid increases the financial burden on remaining users through higher fixed costs and capacity payments.

The impact of BESS adoption will depend on the pace of government investment in grid modernization and the development of advanced markets that enable decentralized battery storage to support the grid.

1.1 BESS Applications Across Multiple Sectors in Pakistan

Improving project economics and high energy prices encourage BESS use across multiple sectors in Pakistan. Solar with BESS (solar + BESS) is common in residential, industrial, and commercial settings. BESS stores cheap electricity produced during the day and discharges it during the evening peak to reduce reliance on the grid (energy arbitrage). Another common application includes battery storage systems for backup power at commercial and residential sites. For industrial applications, BESS may be used to lower fixed charges imposed by the grid based on maximum recorded demand during a specific time. BESS can help lower peak demand, allowing commercial and industrial consumers to leverage time of use (ToU) pricing and lower energy bills.[1]

Additionally, BESS may be useful for advanced applications such as frequency control and system stability, where industries deploy diverse generation options, including weather-dependent solar and wind energy resources.

BESS can provide crucial peak demand management services for the grid. Traditional grids with a high share of DER, such as solar PV, often find it challenging to manage the evening peak demand,

[1] Paulauskas et al. Battery Scheduling Optimization and Potential Revenue for Residential Storage Price Arbitrage. 16 July 2024.

attributed to consumers defecting from the grid during the day but reappearing in the evening. BESS has inherent peak-shaving capabilities and can help flatten the evening demand, reducing the need to ramp up fossil fuel-based plants or add new dispatchable plants.[2]

1.2 Categorization of BESS by Size and Sector

BESS categorization is typically determined by two key factors: storage capacity (measured in kilowatt-hours [kWh] or megawatt-hours [MWh]) and power rating (measured in kilowatts [kW] or megawatts [MW]). These factors determine the system's ability to store energy and provide power when required. For instance, large-scale industrial applications may need systems with a high capacity, typically several MWh, to meet continuous, high-demand energy requirements. Conversely, smaller-scale commercial or residential applications may require BESS systems with lower capacities, ranging from tens to hundreds of kWh, to address more moderate energy needs.

Table 1: BESS Categorization According to Consumer Type and Usage

Consumer Category	Applicable Tariff	Type of Establishment	Sanctioned Load	BESS Usage	Size of BESS (kWh)	Energy Arbitrage (PKR/kWh)
Single-phase residential	Slab-wise progressive tariff	Households with an area of 5 marla (1125sqft) or below	Less than 5kW	Backup power, energy arbitrage, and reduction in fixed charges	2.4kWh or below	1.1-6.5
		Households with an area of 5 - 10 marla (2250sqft)	5kW to 7.5kW		2.4kWh to 5kWh	
Three-phase residential	Time of Use (ToU) (Off-peak/Peak hour rates)	Households with an area of 10 marla to 1 kanal (4500sqft)	7.5kW to 10kW		5kWh to 10kWh	8.3
		Households with an area 1 kanal (4500sqft) or above	10kW or above		10kWh and above	
Commercial	Time of Use (Off-peak/Peak hour rates)	IT centers, medium-sized offices, educational institutes, restaurants, banks, petrol stations	5kW or above	Backup power, energy arbitrage and reduction in fixed charges	20-100 kWh	8.67
		Cold storage, health facilities, educational Institute			100-500 kWh	
Industrial	Time of Use (Off-peak/Peak hour rates)	Rice, flour	Load factor varies according to size and type of industry	Peak shaving, renewable energy integration, optimization of ToU energy usage	1-5MWh	N/A
		Textile, cement, steel			5-20MWh	

Source: Author analysis.

Pakistan’s growing adoption of battery storage is supported by lithium-ion battery imports from China, the global leader in BESS technology and production.

[2] Vetter et al. Lithium-Ion Batteries for Storage of Renewable Energies and Electric Grid Backup. 2014.

China's abundant clean technology manufacturing capacity is forecast to continue expanding, further driving down prices. Bloomberg New Energy Finance (BNEF) predicts batteries will cross the USD100/MWh threshold in 2025, while global benchmarks for wind and solar generation are also expected to decline. BNEF's projections for global levelized cost of electricity (LCOE) benchmarks for battery storage in 2035 show an almost 50% drop, with storage costs declining to USD53/MWh.[3]

While solar PV module prices in Pakistan have consistently declined, emulating improving economics in China, the same is not true for BESS because of high taxes and customs duties. The average price of lithium-ion battery packs in Pakistan ranges between USD230/kWh and USD360/kWh.

Nevertheless, driven by high internal electricity costs and declining solar PV module costs, project economics have improved for solar PV plus BESS installations in Pakistan. Figure 1 shows the levelized cost of solar + BESS installations across various consumer categories and payback periods.

Despite high taxes, combining solar PV with BESS reduces payback periods across all consumer categories. Adding more battery packs to a system will lead to extended payback periods and a higher levelized cost of electricity generation as the overall capital costs of the installation increase. Yet, despite these impacts, solar-battery combinations seem attractive for consumers, with installations continuously increasing.

Table 2: Cost Evaluation and LCOE for Solar + BESS Installations in Pakistan

Consumer Type	Typical Load	System Size (Solar PV)	Energy Feedback to Grid	Other Forms of Electricity Supply	Battery Size	LCOE (PKR/ kWh)	Payback Period (Years)	Energy Supplied via Battery Storage (%)	Total System Cost (Solar + BESS) (PKR mn)
Residential	5-7.5kW	10kW	Yes	National grid	0	13.6	1.5	0	0.95
					5kWh	14.5	2.7	7.6%	1.53
					10kWh	18	3.3	14.9%	1.89
					15kWh	21.5	4.1	21.7%	2.13
					20kWh	25	5	27.8%	2.43
Commercial	50-60kW	100kW	Yes	National grid	60kWh	33.02	4.2	13.8%	13.2
Industrial	4MW	3MW	No	Gas genset (2MW)	3MWh	37.5	5.9	Not calculated	538
		16MW	No (Complete independence from grid)	None (Completely decarbonized generation mix)	48MWh	86.2	Not calculated	Not calculated	4,890

Note: For industrial consumers, the use cases for BESS vary significantly depending on the nature of the industry. Many industries deploy a combination of power generation options, such as diesel and gas-based generators, grid-based imports, and solar PV and BESS. As a result, the payback periods are not straightforward to calculate.
Source: Author analysis.

[3] BloombergNEF. Global Cost of Renewables to Continue Falling in 2025 as China Extends Manufacturing Lead. 06 February 2025.

1.3 Demand Defection and Potential Grid-related Challenges

Due to favorable economics and the opportunity for energy independence, both net-metered and non-net-metered solar PV consumers have caused a decline in grid-based energy demand. This is a significant challenge for the grid, undermining physical distribution infrastructure stability in areas with high solar PV penetration. On a macro level, the falling demand from the grid has led to financial losses and increased capacity payments for the government and remaining consumers.

The government is reconsidering incentives provided to net-metered consumers to moderate solar PV additions, currently at an approximate rate of 300MW per month. However, removing these measures could increase motivation to add BESS to existing solar PV setups, further reducing consumer reliance on the grid or even driving consumers away altogether. Grid defection could unfold in several ways in Pakistan.

1. Adoption of BESS by net-metered consumers

As the government considers tightening regulations for net metering, including reducing buyback rates and limiting system sizes, it is natural for net-metered consumers to progress towards battery storage, having invested substantially in a rooftop solar PV system. If all existing net metering capacity were paired with equal-sized battery storage systems, it could reduce annual electricity demand from the grid by 1.5 terawatt-hours (TWh) or 1.1% of the country's demand in 2024.

2. Adoption of BESS by off-grid and on-grid solar PV installations

Pakistan imported 27.6 gigawatts (GW) of solar PV modules between fiscal year (FY) 2019 and FY2024[4], while another 5.2GW was imported in the first half of FY2025. However, it is estimated that only half of the total imported capacity is currently installed across the country, and at least 11.5GW of this capacity exists off-grid. It is unlikely that all rooftop and captive solar consumers will adopt battery storage systems because of the high upfront costs and modular nature associated with BESS. Moreover, single-phase consumers with smaller households may not have the additional rooftop space required to charge BESS through solar energy.

Similarly, commercial enterprises like office spaces, which operate from 9 AM to 5 PM, may not require battery storage at night. Assuming a conservative estimate where only 25% of the energy produced by the imported solar panel capacity is stored, annual grid demand could be reduced by 11.5TWh, or 8.4% of Pakistan's actual demand in 2024 (137TWh).[5]

[4] Renewables First. The Great Solar Rush in Pakistan. 2024.
[5] NEPRA. State of the Industry Report 2024. Accessed on 28 April 2025.

3. Energy demand reduction based on BESS imports

A more direct way of assessing BESS adoption is by examining lithium-ion battery storage imports. According to analysis by the Institute for Energy Economics and Financial Analysis (IEEFA), around 1.25GWh of lithium-ion battery storage packs were imported into Pakistan in 2024. This accounts for around 4.7% of that year's 25.6GW annual peak demand. Based on a daily charging-discharging cycle, installing the entire 1.25GWh of battery storage could mean a yearly deduction of 438GWh of energy demand from the grid.

IEEFA estimates that BESS imports could increase to 8.75GWh by 2030 if business as usual persists and the annual addition of BESS remains at 1.25GWh. However, this represents 26% of the National Transmission and Despatch Company's (NTDC) projected peak demand of 34GW in 2030 and could lead to the underutilization of expensive liquified natural gas (LNG) peaking plants, which are locked into the grid for the next 23-28 years.[6]

Currently, BESS adoption levels remain moderate but could amplify grid-related challenges in the future as they increase. Power generation expansion planning aims to meet the peak demand experienced by the power sector for only a few hours annually. The capacity contracted is for a long-term basis with fixed capacity payments, regardless of actual plant utilization.

This has led to overcapacity and economic inefficiencies in the national grid, resulting in increased consumer tariffs. The growing trend of solar PV capacity is projected to have reduced grid demand by almost 10-12TWh in 2024. According to government estimates, net-metered solar PV capacity led to an excess of PKR159 billion in grid storage costs and capacity payments, which consumers bore through a PKR1.5/kWh tariff hike.[7]

With increased BESS installations, consumers are expected to discharge their batteries during peak hours, reducing peak demand gradually and leading to further grid redundancy.

1.4 Policy Recommendations

Pakistan's rapid adoption of distributed energy systems, while positive for advancing the country's clean energy goals, creates the need to manage this transition securely without putting the grid in an expected "utility death spiral".[8] Grid planners and policymakers need to envision how to keep the grid afloat with appropriate incentives and costs while managing the addition of distributed solar and battery storage.

Several strategic, regulatory, and technical steps should be taken.

[6] The oldest LNG-based plant in Pakistan, Haveli Bahadur Shah Power Plant, is 7 years old, while the youngest, Trimmu LNG plant is only 2 years old. The plants have been contracted for a lifetime of 30 years.
[7] The News. Roof solar net metering shifts Rs159bn burden on grid consumers. 09 March 2025.
[8] PV Tech. Disco death spiral looms amid Pakistan's 'perfect storm' of rooftop solar domination. 31 January 2025.

1. **Improve distribution system planning process (Bottom-up approach using advanced predictive techniques)**

   A feeder-wise, bottom-up load forecasting methodology is recommended to reflect localized demand dynamics more accurately. This method allows for granular insight into consumption patterns, the impact of DERs, and local constraints, which are often overlooked in top-down forecasting methods. This can lead to a more realistic estimation of future capacity requirements, helping avoid over-procurement or underutilized infrastructure investments.

2. **Strategic addition of centralized generation capacity**

   Pakistan is struggling to manage rapidly rising levels of solarization amid an oversupply of generation capacity, which is further threatened by the addition of battery storage systems. To avoid this, the government may have to temporarily stall any new capacity additions while assessing the improving economics of solar + BESS installations across the region. Shifting contracts to a 'take and pay' basis, where utilities pay only for actual energy purchased from plants, could also prevent peaking plants from becoming stranded assets.

3. **Adopting the correct regulatory framework to optimize BESS additions**

   Successful DER induction requires provisions for hosting capacity analysis of short- and long-term adoption in the distribution network. Therefore, the distribution code should be updated, and modern control and monitoring mechanisms should be mandated for the distribution system operator's visibility.

4. **Grid modernization and digitization to support renewable energy and battery storage integration**

   The diverse location of DER and energy feedback from significant rooftop solar PV installations across main load centers in Pakistan are currently causing issues. These include reverse power flow and negative loading on distribution transformers in feeders with excessive rooftop solarization. Resolving these challenges requires modifications to grid infrastructure, including widespread adoption of smart meters, consumer and transformer monitoring systems (asset performance management), and feeder-level automation and modernization. A cohesive Information and Communications Technology (ICT) strategy is also needed to transmit collected data to control centers and enhance existing data communication networks.

5. **Maximizing benefits from BESS - Aggregating DER into virtual power plants**

   Behind-the-meter (BTM) battery storage deployment at an individual household or commercial level can provide the same functional benefits as utility-scale battery storage. Individual household battery systems can be aggregated into virtual power plants (VPPs), controlled externally by third-party aggregators or the utility, allowing participation in electricity markets. On an aggregated level, VPPs can provide ancillary services like voltage support, reactive power compensation, and frequency regulation. However, successful implementation is highly dependent on the level of grid modernization and deployment of smart metering that Pakistan can afford.

Battery energy storage systems are rapidly becoming a cornerstone of modern energy infrastructure, offering significant benefits across residential, commercial, and industrial sectors. These benefits range from peak load reduction and energy cost savings to improved reliability and power quality. The technical characteristics of the grid and the type of regulatory frameworks available are crucial factors in determining the right use case for batteries. Pakistan's high penetration of rooftop solar generation can provide a strong foundation for large-scale battery storage adoption in a distributed manner.

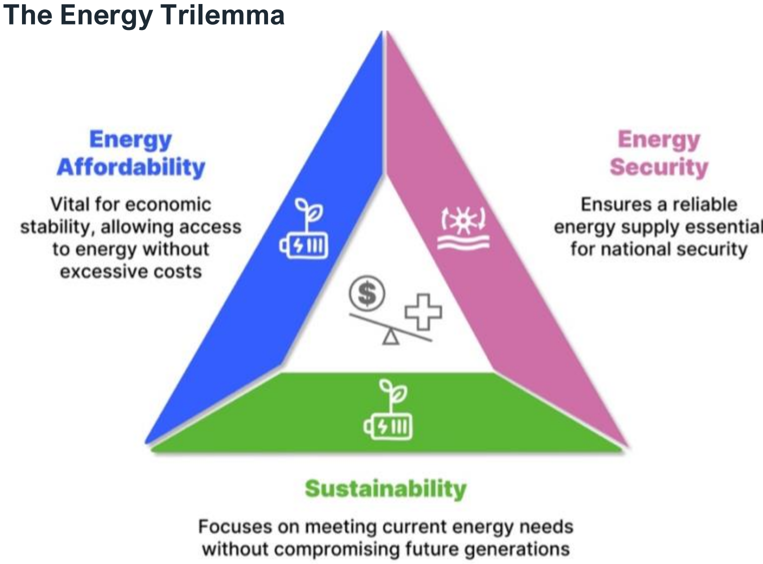
If sustained through further fiscal support and regulatory incentives, this could mean minimal investment requirements for new generation assets for the government at a central level.

However, a lack of grid modernization and strong regulatory support remain key barriers that should be addressed to ensure Pakistan's energy transition happens efficiently without jeopardizing the future of the national grid.

2. Introduction

Pakistan's energy transition has witnessed significant changes over the decades, driven by the persistent challenge of the energy trilemma — balancing energy security, affordability, and sustainability. Energy security concerns have often prevailed, resulting in continued reliance on imported fossil fuels, such as furnace oil and liquefied natural gas (LNG), for power generation. This dependency has resulted in vulnerabilities to global price volatility and economic shocks, exposing Pakistan's economy to currency depreciation impacts and international competition for fuel procurement. Consequently, energy supplies have been less secure. Unlike current national energy policies prioritizing competitiveness and environmental sustainability, policies in the past emphasized capacity addition in power sector planning, leading to entrenched inefficiencies. In addition to a generation capacity surplus, Pakistan now contends with a transmission and distribution network with high losses and theft, low tariff recoveries, and little incentive for utilities to improve their economic performance. As a result, electricity prices in the country have increased sharply in the past five years, rising from USD12 cents per kilowatt hour (¢/kWh)[9] in 2019-2020[10] to USD17¢/kWh in 2024.[11,12]

Figure 1: The Energy Trilemma



Source: Adapted from Energy Asia's "Balancing the energy trilemma for a just transition".[13]

Complex regulatory procedures, contractual obligations towards existing power generation capacity, and a challenging investment landscape have prevented the widespread uptake of renewable energy resources at the utility scale in Pakistan. However, because of the continually rising costs of fossil-

[9] According to USD-PKR parity in 2019.
[10] Lahore Electric Supply Company (LESCO). Retail Electricity Prices 2019.
[11] Author calculations based on retail rates supplied by LESCO.
[12] According to USD-PKR parity in 2024.
[13] Energy Asia. Balancing the Energy Trilemma for Just Energy Transition. Accessed on 15 May 2025.

fuel based generation, Distributed Energy Resources (DER) are on the rise in Pakistan due to their economic competitiveness.

DERs are small-scale energy assets, like rooftop solar panels or battery storage, that generate, store, or consume energy locally, often near where it is produced. Rising energy prices and falling DER costs have pushed consumers to adopt decentralized energy solutions, enabling reduced reliance on the grid and lower energy costs.

After a sharp decline in solar photovoltaic (PV) module prices in China, Pakistan has established itself as the world's sixth-largest solar market and the third-biggest market for Chinese solar PV exports.[14] According to data from Ember and Renewables First, the country imported 5.2 gigawatts (GW) of solar panels from China in the first six months of fiscal year (FY) 2025. Between FY2022 and the first two quarters of FY2025, Pakistan imported a total of 29.2GW solar capacity.[15] Over 15GW of this capacity has reportedly been installed across residential rooftops and commercial and industrial sites.[16] One-fourth or 4.1 gigawatts (GW) is net-metered and allowed to sell output to the grid.[17]

Battery Energy Storage Systems (BESS) are emulating the price drop witnessed by solar PV modules. In December 2024, Bloomberg New Energy Finance (BNEF) reported a 20% price drop in lithium-ion battery pack prices compared to 2023. According to BNEF, average prices for stationary storage systems closed at USD115/kWh[18], the sharpest decline recorded worldwide since 2017. The figure represents a global average, with prices varying upwards or downwards in different regions depending upon local conditions and manufacturing capabilities.[19] China, for instance, held its biggest energy storage auction in December 2024, where bid prices for battery storage systems averaged USD66.3/kWh, and included services such as system design, installation guidance, commissioning, long-term maintenance, and integrated safety features.[20]

Pakistan currently imports most of its lithium-ion batteries from China. Declining prices driven by Chinese technological efficiencies, competition, and a manufacturing boost will directly impact battery storage adoption in the country. Increasing battery system adoption threatens Pakistan's traditional utility model, which is planned according to the maximum peak load experienced throughout the year. Continuing on this established path despite rising DER deployments could exacerbate the oversupply of installed capacity in the power sector, resulting in underutilization of energy infrastructure and higher energy costs.

---

[14] World Economic Forum. Pakistan is experiencing a solar power boom. Here's what we can learn from it. 25 November 2024.
[15] Renewables First. The Great Solar Rush in Pakistan, The Momentum Continues. 30 January 2025.
[16] Business Recorder. Solar showdown: the untold power play behind Pakistan's energy revolution—II. 31 October 2024.
[17] Business Recorder. From crisis to clean energy: Pakistan emerges as top solar market in 2024. 14 April 2025.
[18] The figure represents investment costs for lithium-ion battery packs and does not include the cost of delivered energy. Lithium-ion battery packs are usually rated in terms of energy output in kWh.
[19] Bloomberg New Energy Finance. Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to $115 per Kilowatt-Hour. 10 December 2024.
[20] Renew Economy. "Mind blowing:" Battery cell prices plunge in China's biggest energy storage auction. 17 December 2024.

The rapid adoption of solar PV systems in Pakistan has already started impacting centralized generation on the grid. As more consumers shift to net metering and self-generation, the overall electricity demand from the national grid has started declining. Due to contractual obligations resulting from long-term power purchase agreements, the exit of paying consumers from the grid leads to an increase in fixed costs or capacity payments for remaining users. For instance, grid-based power generation declined by 10% while capacity payments rose by 29% in FY2023.[21] The government also claims that net metering resulted in a financial impact of PKR103 billion on non-net metered consumers in FY2024.[22, 23]

This is a worrying trend for the government, which relies on grid-based revenue to fund the maintenance and expansion of the country's power infrastructure. In response, the government intends to act, including but not limited to revising net metering regulations, reducing incentives for grid-connected solar systems, and introducing 'winter packages'[24], which incentivize higher consumption from the grid in exchange for reduced electricity tariffs. Grid modernization is also being pursued to allow more distributed generation integration in the country's conventional grid.

Increased power injection from solar PV sources causes the grid to become low in inertia and prone to technical issues such as high consumer voltages, voltage fluctuations, low power factor, reverse power flows, and high stress on distribution transformers. Adopting BESS with solar PV systems could present a potential solution, as observed globally. For instance, markets such as the Electric Reliability Council of Texas (ERCOT), California Independent System Operator (CAISO), and Australia's National Energy Market (NEM) are quickly adopting BESS at the utility and commercial and industrial scale. Residential-scale BESS is also incentivized in the Australian region. These battery systems improve grid reliability by providing voltage and frequency support services on a rapid response basis.

This report aims to highlight the advantages of BESS by exploring its use cases across various sectors, including residential, commercial, and industrial applications. It provides real-world, practical examples of BESS systems already installed in these sectors, demonstrating the tangible benefits and potential of this transformative technology.

A financial analysis is also conducted using simulations to estimate the payback period for residential, commercial, and industrial BESS.

Furthermore, the report addresses a critical emerging trend: energy defection from the grid. By projecting the future increase in BESS demand given current circumstances in Pakistan, it evaluates the potential impact of significant numbers of consumers exiting the grid. It assesses how the country's energy sector may be reshaped.

[21] Profit. The double whammy of declining electricity demand and increased consumer tariffs. 29 July 2024.
[22] Arab News. Pakistan's energy minister says net metering billing system for solar power unsustainable. 28 January 2025.
[23] The Express Tribune. Solar net metering adds Rs103b burden on grid power consumers. 27 January 2025.
[24] Business Recorder. 'Winter package': Nepra approves Rs26.07 per unit relief for 3 months. 07 December 2024.

3. Consumer Types & Use Cases

BESS enables consumers to store excess energy in times of over-production from renewable energy systems on the grid and utilize it during periods of grid outages or 'peak hours' when electricity production is expensive. Solar with BESS (solar + BESS) is a common combination in Pakistan's residential, industrial, and commercial scenarios. BESS stores cheap electricity produced during the day and discharges it during the evening peak to reduce reliance on the grid. Consumers can optimize energy costs and ensure a steady electric power supply and independence from the grid.

BESS adoption has the potential to reshape Pakistan's energy landscape, driving the shift toward a more decentralized, consumer-centric system while presenting new challenges (in the form of energy defection) and opportunities for the energy sector.

3.1 Residential Use Cases for BESS

3.1.1 Backup Power

Backup power is one of the most common residential use cases for lithium-ion batteries. It provides a reliable energy source during grid outages, which are frequent in Pakistan due to aging grid infrastructure, unsustainable dependence on imported fuels, and financial liquidity issues. Battery systems are particularly valuable in distribution areas prone to power interruptions or unstable electricity supply because of poor grid conditions. When the grid fails, a battery system seamlessly supplies power to critical household loads, such as lighting, refrigeration, medical equipment, and communication devices.[25] For example, a 10 kilowatt-hour (kWh) lithium-ion battery can power essential home appliances for several hours depending on the rate of energy consumption. Combined with solar panels, the battery can recharge during the day, extending its utility during prolonged outages. This solution enhances energy security and eliminates reliance on fossil fuels, contributing to a more sustainable energy footprint.

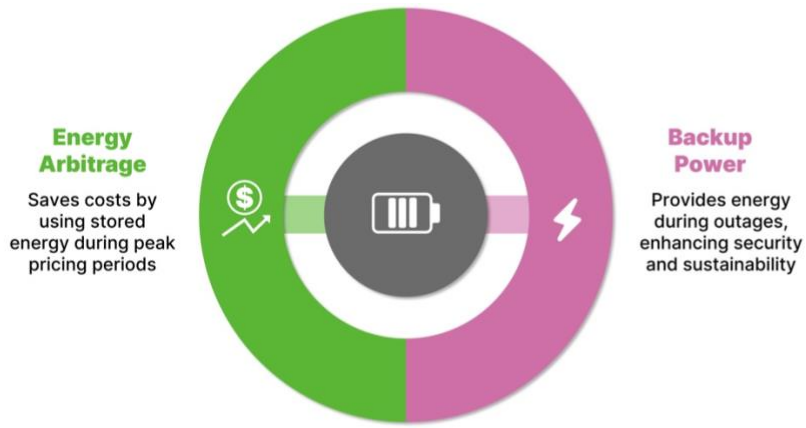
3.1.2 Energy Arbitrage

Energy arbitrage involves leveraging time of use (ToU) or dynamic pricing by storing energy when electricity prices are low (in off-peak hours) and using it during periods of high demand when rates are higher.[26] Pakistan currently uses a ToU pricing system for three-phase residential consumers who pay separate rates for off-peak (usually daylight) and peak hours (evening). Residential lithium-ion battery systems enable homeowners to maximize savings by charging from the grid or solar PV systems at cheaper rates and discharging stored energy during peak pricing periods.

[25] Vetter et al. Lithium-Ion Batteries for Storage of Renewable Energies and Electric Grid Backup. 2014.
[26] Paulauskas et al. Battery Scheduling Optimization and Potential Revenue for Residential Storage Price Arbitrage. 16 July 2024.

For example, a homeowner with a battery system can charge the battery during off-peak rates and power their home during the peak rate period, avoiding expensive peak-hour charges. Energy arbitrage reduces electricity bills and contributes to grid stability by balancing demand and reducing strain during peak periods. Additionally, pairing a battery system with solar energy storage can optimize savings and energy independence, making it an attractive solution for cost-conscious households.

Figure 2: Residential Lithium-ion Battery Use Cases



Source: Author analysis.

3.2 Commercial Use Cases for BESS

3.2.1 Backup Power

BESS is pivotal in providing backup power for commercial businesses, ensuring operational continuity during power outages or grid disruptions. Unlike traditional backup solutions such as diesel generators, BESS can respond instantly, transferring critical loads to stored energy without delay. This immediate response capability is crucial for commercial establishments like banks, information technology (IT) centers, healthcare facilities, and retail outlets, where even a momentary power disruption can lead to significant operational, financial, or reputational losses. Critical systems such as servers, point-of-sale terminals, automated teller machines (ATMs), surveillance systems, and medical equipment can be prioritized and automatically shifted to BESS during an outage, ensuring uninterrupted services and safeguarding essential functions.

3.2.2 Energy Price Arbitrage

i. **Reduction in Fixed Charges**

In addition to a fixed connection charge for each consumer category, the National Electric Power Regulatory Authority (NEPRA) imposes fixed charges for all consumers based on their energy consumption, connection type, and the Maximum Demand Indicator (MDI) - the highest amount of electricity required by a specific consumer during a given period (see Section 3.1 for more details).[27]

Fixed charges based on the observed MDI incentivize consumers to optimize their energy demand. Installing a BESS can help reduce peak load (MDI), lowering the fixed charges applied on a per kilowatt (kW) basis.

ii. **Leveraging Time of Use (ToU)**

For commercial consumers, ToU tariffs help optimize energy costs by strategically shifting energy consumption patterns, similar to residential ToU. BESS enables commercial businesses to leverage ToU tariffs effectively, reducing energy costs and improving operational efficiency.

3.3 Industrial Use Cases for BESS

3.3.1 Peak Shaving

Peak shaving is a critical commercial use case for lithium-ion batteries in the Commercial and Industrial (C&I) sector, designed to reduce energy demand during peak hours. Businesses often face high demand charges, which can comprise a significant portion of their electricity bills. A lithium-ion battery system stores energy during low-demand periods or charges from renewable sources like solar panels. This stored energy is then discharged during peak hours to reduce grid reliance.

For example, an industrial facility with heavy machinery might experience a spike in energy use during production hours. Consequently, the industrial consumer will face 'maximum demand' charges. A suitable lithium-ion battery can offset these peaks, lowering demand charges and increasing savings annually.

3.3.2 Optimized Time of Use

For many industrial facilities, especially those with high energy consumption, these ToU fluctuations can represent a significant portion of their energy costs. The challenge is that industrial operations often need consistent power throughout the day, and renewable energy production is intermittent. For instance, solar energy generation peaks during the day, but industrial demand often spikes in the evening when solar generation drops.

During periods of low electricity demand (off-peak), such as midday when solar energy production is high, BESS can store the surplus renewable energy in large-scale batteries.

[27] Central Power Purchasing Authority (CPPA-G). Standard Operating Procedures.

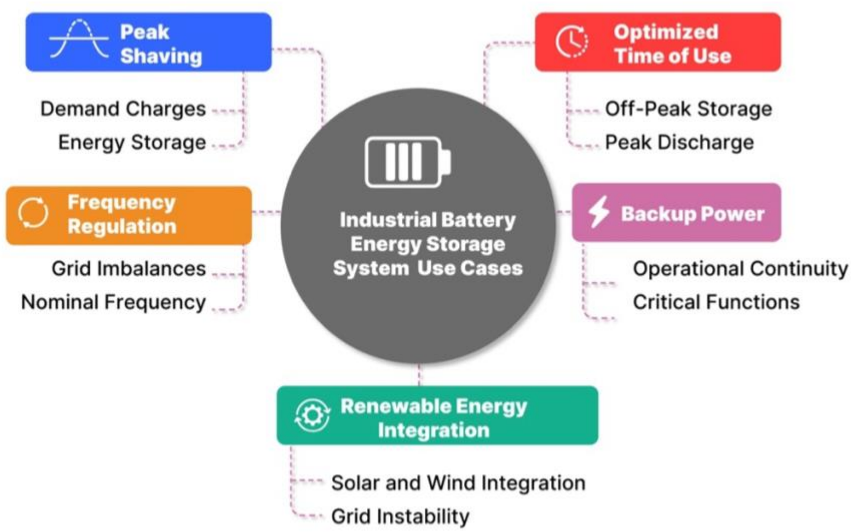
This is particularly advantageous when renewable energy sources like solar power generate more electricity than the industrial facility needs.

When demand for electricity peaks, such as during the evening hours when industrial processes might still be running but renewable generation is unavailable (after sunset for solar), BESS can discharge its stored energy. This reduces the facility's reliance on the grid, which charges significantly higher rates during peak hours. By discharging stored energy during these high-demand times, the industrial facility avoids purchasing electricity at premium rates. The stored energy acts as a buffer, allowing the business to operate at optimized energy costs.

3.3.3 Backup Power

Backup power is essential to ensure the continuity of industrial operations during power outages, avoiding downtime, and maintaining critical functions. Industries often rely on equipment that cannot afford to lose power, such as computerized machines (computer numerical control) in the textile manufacturing sector and medical devices in the pharmaceutical industry, which require consistent cooling. Backup power systems ensure that these machines continue running or are safely powered down during a blackout, preventing costly damage or loss of productivity. BESS can provide immediate and reliable backup power to keep these critical machines operational until the main grid supply is restored or a generator kicks in.

Figure 3: Industrial Use Cases for BESS



Source: Author analysis based on various sources.[28]

[28] Wic Power. Revolutionizing Energy Storage: The Rise of BESS in Commercial and Industrial Applications. 2023. Accessed on 15 May 2025.

3.3.4 Frequency Regulation

Frequency regulation is a critical use case for BESS in industrial settings, especially in regions where the grid experiences fluctuations due to high demand, generation imbalances, or intermittent renewable energy sources. Maintaining a stable frequency is essential for reliable grid operation. In Pakistan, the standard frequency is 50 Hertz (Hz), and any deviation can affect industrial machinery operations, potentially leading to inefficiencies, system failures, or equipment damage.

BESS can help stabilize the grid frequency by responding quickly to imbalances in supply and demand. When the grid frequency drops (indicating demand exceeds supply), BESS can discharge stored energy into the grid to boost supply and bring the frequency back to its nominal value. Conversely, if the grid frequency rises (indicating supply exceeds demand), BESS can absorb and store excess power, preventing system overload and lowering frequency.

3.3.5 Renewable Energy Integration and Management

BESS is vital in ensuring a continuous and stable energy supply in industries that rely on multiple renewable energy sources like wind and solar power. For example, an industry may utilize solar, wind, and conventional thermal-based grid power generation to meet its energy needs. Solar energy is abundant during the daytime but can decrease suddenly due to cloud cover. Wind power is more consistent at night but can fluctuate depending on seasonal patterns. The grid is available throughout the day but is unreliable due to frequent outages and load shedding.

In such a scenario, BESS serves as a critical component by storing surplus energy generated from solar and wind power when these sources produce more energy than the facility requires (during the daytime for solar and at night for wind energy). When solar power declines or wind energy production is insufficient, BESS discharges its stored energy to bridge the gap and ensure that the facility remains powered. Additionally, when the grid supply becomes unstable due to load shedding or power outages, BESS can supply the necessary energy, minimizing operational disruptions and reducing grid dependency.

By effectively managing the fluctuating availability of solar and wind energy and compensating for grid power unreliability, BESS enables the industrial facility to operate smoothly with reduced energy costs. It also enhances energy security by ensuring a reliable power supply during periods of low renewable generation or grid instability.

4. Categorization of BESS by Size and Sector

To understand the potential of BESS, it is essential to categorize these systems based on their size and suitability for different sectors. This report focuses primarily on three key sectors — industrial, commercial, and residential — and aims to classify BESS in terms of storage capacities and specific applications within each sector. Although other sectors, such as off-grid systems, microgrids, and utility-scale energy storage, also benefit from BESS, they have not been included in the scope of this study.

The categorization of BESS is typically determined by two factors: storage capacity (measured in kilowatt-hours [kWh] or megawatt-hours [MWh]) and power rating (measured in kilowatts [kW] or megawatts [MW]). These factors determine the system's ability to store energy and provide power when required. For instance, large-scale industrial applications may require systems with high capacity, typically several MWh, to meet continuous, high-demand energy requirements. Alternatively, smaller-scale commercial or residential applications may require BESS systems with lower capacities, ranging from tens to hundreds of kWh, to address more moderate energy needs.

Consumers can optimize energy management strategies, reduce operational costs, and enhance energy reliability by understanding how BESS capacities correlate with sector-specific requirements.

4.1 Residential Consumers

In residential applications, BESS is primarily designed to provide backup power, optimize energy consumption, and enhance energy independence. These systems are typically smaller in capacity but highly effective for homes with solar energy configurations or areas with frequent power outages.

According to Pakistan’s tariff categories, there are two types of residential consumers.

i. **Single-phase consumers**

These consumers typically have lower peak load requirements, generally under 5kW. This category includes smaller residential settings, such as 5-marla (1125 square feet [sqft]) homes and other smaller dwellings. The energy tariff is structured using a slab-based system for these consumers, where energy charges increase with higher consumption levels. This provides an opportunity for energy arbitrage using BESS integration to lower energy consumption profiles and reduce the economic impact of remaining consumption by switching to a lower-tariff slab.

Table 3: Energy Price Arbitrage Details for Single-Phase Consumers

Fixed charges per slab (PKR)	Start of Slab (kWh)	End of Slab (kWh)	Unit Rate (PKR/kWh)	Energy Price Arbitrage from Previous Slab (PKR/kWh)
-	0	100	23.59	6.48
-	101	200	30.07	4.19
-	201	30	34.26	4.89
200	301	400	39.15	2.21
400	401	500	41.36	1.42
600	501	600	42.78	1.14
800	601	700	43.92	4.92
1000	Above 700		48.84	

Note: The value of energy arbitrage is calculated by subtracting the applicable tariff rate for a consumption slab from that of its succeeding slab.
Source: Islamabad Electric Supply Company.

ii. Three-phase residential consumers

These consumers, typically those with larger homes or energy-intensive appliances, are subject to the ToU tariff system, which has two distinct blocks: peak and off-peak hours. A higher tariff applies to peak hours, while off-peak hours are cheaper, usually applicable overnight or during midday when energy demand is lower.

Table 4: Energy Price Arbitrage for Three-Phase Consumers

Time of Use (ToU)	Rates per Unit (PKR/kWh)	Energy Arbitrage (PKR/kWh)
Off-Peak Hour	41.68	8.3
Peak Hour	49.98	

Note: The value of energy arbitrage is calculated by subtracting the applicable tariff rate for off-peak consumption from that of peak hour consumption.
Source: Islamabad Electric Supply Company.

iii. Fixed charges for residential consumers

NEPRA imposed fixed charges on all consumer categories starting in July 2024.[29] This was in addition to regular energy charges proportional to electricity imports from the grid. For single-phase residential consumers, fixed charges vary from PKR200 to PKR1,000 per month based on the applicable energy consumption slab. The regulator imposed a monthly fixed charge fee of PKR1,000 per connection for three-phase consumers. These monthly fixed charges indirectly incentivize BESS as residential consumers must pay an annual fixed fee ranging from PKR2,400 to PKR12,000.

In Pakistan, sanctioned load for residential consumers is allocated based on property size[30]:

- 5 marla (1125sqft) and below: 5kW of sanctioned load
- 5-10 marla (1125sqft to 2250sqft): 7.5kW of sanctioned load
- 1 kanal (4500sqft) and above: 10kW to 15kW of sanctioned load

These sanctioned loads are essential for determining the capacity and specifications for residential BESS, ensuring that the system is sized appropriately to meet peak load demand and maximize energy savings.

Table 5 shows typical battery sizes based on these factors, while common battery types and configurations are provided in Section 10.1.

Table 5: Residential BESS Capacity Range

Household Size (Area)	Consumer Tariff Category	Sanctioned Load	Typical PV Capacity Installed	Approximate Battery Capacity
5 marla and below	Single-phase	5kW or below	5kW or below	2.4kWh or below
5 to 10 marla	Single or Three-phase	5kW to 7.5kW	5kW to 10kW	2.4kWh to 5kWh
10 marla to 1 kanal	Three-phase	7.5kW to 10kW	5kW to 10kW	5kWh to 10kWh
1 kanal and above	Three-phase	10kW and above	10kW and above	10kWh and above

Note: Minimum quantity based on 50% of the size of solar PV installation.
Source: Author analysis.

[29] Samaa News. Electricity bills revised fixed charges for domestic consumers. 02 July 2024.
[30] NEPRA. Consumer Service Manual. January 2021.

4.2 Commercial Consumers

In commercial settings, BESS primarily serves as backup power, which addresses the need for uninterrupted operations during grid outages or fluctuations. This is particularly significant for businesses where even a brief power disruption can result in operational inefficiencies, data loss, or financial setbacks.

The commercial sector typically includes medium-sized offices in urban settings, such as office plazas, shopping centers, educational institutes, IT centers, petrol stations, banks, coworking spaces, cold storage, restaurants, medium-sized clinics or health facilities, and small and medium-sized enterprises (SMEs). Electric vehicle charging stations (EVCS) are also considered a commercial entity.

These establishments often have higher energy demands than residential settings but are less energy-intensive than large-scale industrial facilities. Nevertheless, due to their critical operations, continuous power is a necessity.

Figure 4: BESS Commercial Applications

Source: Author analysis.

According to Pakistan's grid code, commercial establishments are categorized as:

i. Commercial consumers with a load less than 5kW
ii. Commercial consumers with a load of 5kW or above without ToU
iii. Commercial consumers with a load of 5kW or above with ToU
iv. Electric vehicle charging stations (EVCS)

Subsequently, a specific tariff slab applies to each category depending on the sanctioned load and ToU.

Table 6: Energy Price Arbitrage for Commercial Consumers

Time of Use (ToU)	Rates per Unit (PKR/kWh)	Energy Arbitrage (PKR/kWh)	Fixed Monthly Charges (PKR/kW)
Off Peak Hour	36.30	8.67	1250
Peak Hour	44.97		

Source: Author analysis.

Fixed charges on commercial applications

The regulator has imposed a fixed monthly charge of PKR1,000 per connection for consumers with a load less than 5kW. For commercial loads above 5kW, monthly charges of PKR1,250 per kW are applied. Where fixed charges are applicable on a monthly capacity (kW/month) basis, the capacity (kW) is either 25% of the sanctioned load or the observed MDI, whichever is higher. These fixed charges can be material for larger establishments, leading to a higher possibility of shifting to BESS.

Table 7 includes battery sizing options for various commercial uses.

Table 7: Commercial Application BESS Capacity Range

Commercial Application	Approximate Sanctioned Load (kW)	Typical PV Capacity Installed (kW)	Approximate Battery Capacity (kWh)
Petrol station	50-100	50	50-100
Bank	30-40	25-50	20-50
IT Center	50-80	50-100	100
Health Facility	50-100	100	50-100
Educational Institute	100-500	250-1000	500
Cold Storage	500-1000	300-1000	100-500
Electric Vehicle Charging Station	50-100	50-100	50-100

Source: Author analysis.

4.3 Industrial Consumers

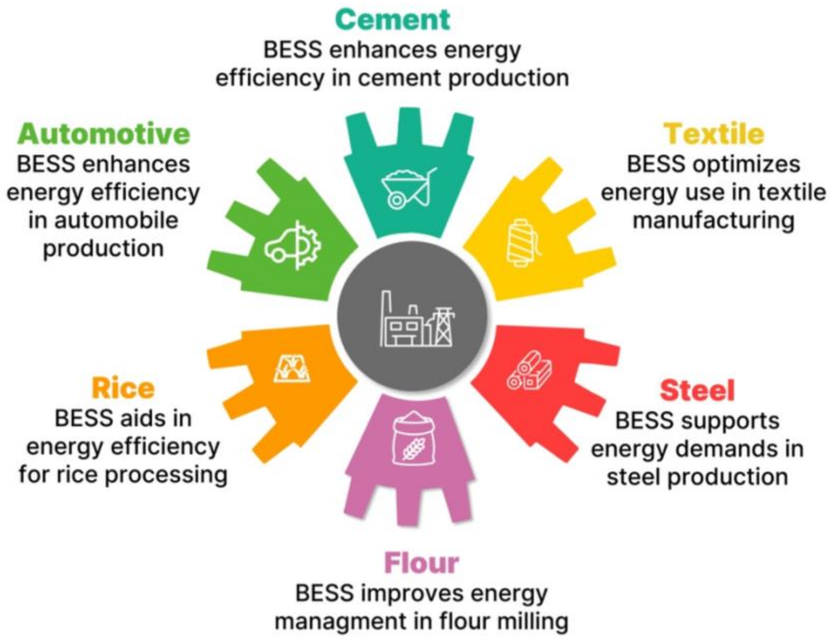
BESS configurations in the industrial sector are utilized in varying capacities based on the specific energy requirements of each sub-sector, determined by manufacturing processes and operational demands. For instance, spinning, weaving, dyeing, and finishing operations in the textile industry rely on continuous, high-precision power supply for machines and temperature-controlled environments. Even minor power disruptions can cause production delays, fabric defects, or material wastage. A medium-capacity BESS can provide backup power, stabilize grid supply, and reduce peak energy costs, ensuring uninterrupted operations.

In contrast, the cement industry, which involves energy-intensive processes like crushing, grinding, and kiln operations, requires significantly larger BESS configurations. Cement production depends on heavy machinery and rotary kilns that operate continuously, consuming vast amounts of power. Large-scale BESS are deployed to manage peak energy demands, reduce grid dependency, and optimize energy costs by utilizing stored power during peak tariff hours. Similarly, flour or rice mills have less energy-intensive but highly time-sensitive processes, like grinding and milling, where short power interruptions can disrupt batch processing and quality. Small-to-medium BESS configurations are ideal for these operations, providing backup power to keep equipment running and reduce operational losses.

Steel mills require extremely high energy capacities due to heavy machinery operating under extensive power loads, such as electric arc furnaces, rolling mills, and smelting units. Large-capacity BESS configurations are essential for load leveling, peak shaving, and continuous power supply during high-demand periods. The deployment of BESS in the industrial sector is customized based on each industry's unique energy consumption patterns and manufacturing processes.

Additionally, export-oriented or environmentally conscious industries may have renewable energy targets for their energy mix, leading them to install solar PV or wind turbines to diversify energy sources.

Figure 5: Industrial BESS Applications



Source: Author analysis.

The tariff structure for industrial consumers is based on the point of connectivity with the distribution grid. Four categories utilize ToU and fixed charges based on MDI or sanctioned load. The fixed monthly charges are PKR1,250 per kW, based on a 25% sanctioned load or actual MDI, whichever is higher.

Industrial load is usually on the higher side. Table 8 shows the typical power loads in various industries.

Table 8: Industrial Load Type and Battery Capacity Ranges

Industry Type	Battery Ranges (MWh)
Textile	5-10
Cement	10-20
Steel	10-20
Rice	1-5
Flour	1-5

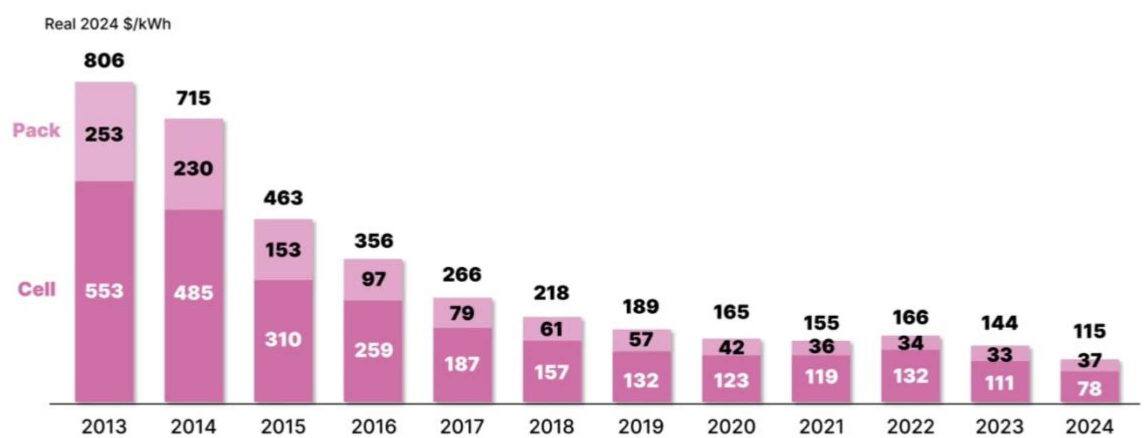
Note: It was difficult to assess typical loads for the industrial segment due to a high level of variation within industries depending on the type and size of establishment.
Source: Author analysis.

5. Financial and Economic Analysis

The rapid uptake of BESS can significantly impact the power sector. According to the International Energy Agency (IEA), battery costs have declined by 90% in less than 15 years. 2023 proved to be a pivotal year as utility-scale batteries paired with solar PV became competitive with new coal-based power projects in some countries like India.[31]

The IEA predicts a further 40% decline in the cost of lithium-ion battery storage by 2030. This is evident as BloombergNEF's most recent levelized cost of electricity (LCOE) estimate for battery storage systems in February 2025 was USD104/MWh, a 30% year-over-year (YoY) decline from 2023. Meanwhile, lithium-ion battery pack prices averaged at USD115/kWh, a 20% YoY decline from global benchmarks in 2023.[32]

Figure 6: Volume-weighted Average Lithium-ion Battery Pack and Cell Prices, 2013-2024



Note: Historical prices have been updated to reflect real 2024 dollars. Weighted average survey value includes 343 data points from passenger cars, buses, commercial vehicles, and stationary storage.
Source: Bloomberg New Energy Finance (NEF).[33]

These low prices can be attributed to the recent extensive BESS overcapacity in mainland China, which dominates the global battery manufacturing market, with almost two-thirds of the top 100 battery developers in the world located there.

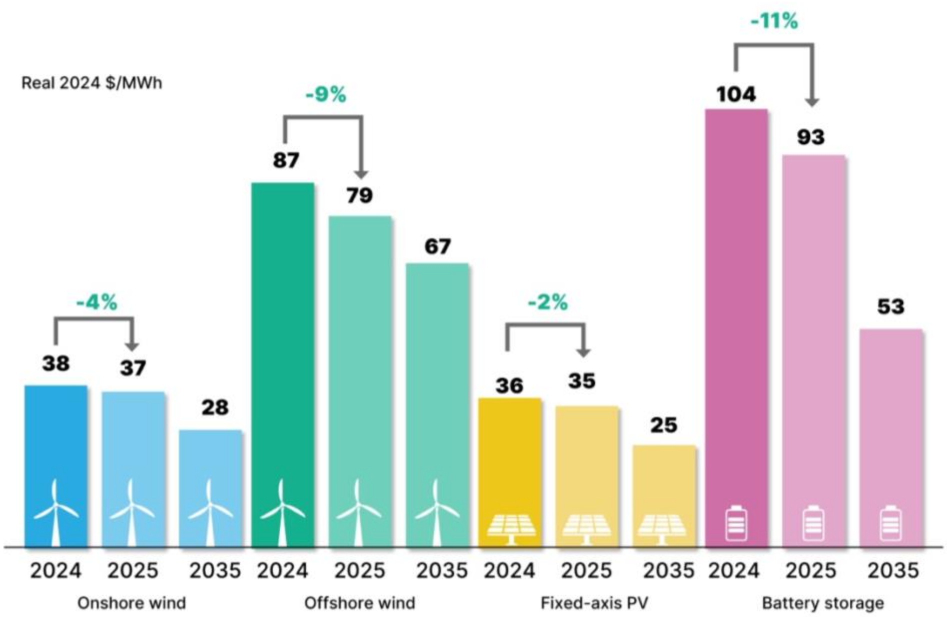
Other factors that contribute to lower prices are stable raw material supply chains. Technological improvements in battery manufacturing and design lead to more efficient and cost-effective storage solutions. For example, lithium-ion cell design has evolved from smaller formats to larger, more

[31] International Energy Agency (IEA). Batteries and Secure Energy Transitions.
[32] BloombergNEF. Global Cost of Renewables to Continue Falling in 2025 as China Extends Manufacturing Lead. 06 February 2025.
[33] BloombergNEF. Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to $115 per Kilowatt-Hour. 10 December 2024.

efficient structures. The newer cells offer significantly higher energy density, improved thermal management, and reduced manufacturing complexity. Modern pouch and prismatic cells have also increased in capacity and are designed for tighter integration into battery packs, reducing inactive materials and improving overall system efficiency.[34, 35]

Additionally, increasing BESS market players intensify competition and drive down prices. Mainland China's abundance of clean technology manufacturing capacity is forecast to continue, reducing technology prices further. BNEF predicts batteries will cross the USD100/MWh threshold in 2025, while global wind and solar generation benchmarks are also expected to decline. An almost 50% drop can be seen in BNEF's projections for global LCOE benchmarks for battery storage in 2035, with the cost of storage declining to USD53/MWh.[36]

Figure 7: BNEF's LCOE Outlook for Battery Storage Clean Energy Technologies, 2024, 2025, 2035



Note: LCOEs reported without subsidies or tax credits. Offshore wind includes transmission costs. Battery storage reflects four-hour systems.
Source: BloombergNEF.[37]

[34] Enerpoly. The Future of Energy Storage: 7 Trends to Follow. 19 December 2024.
[35] Ciez et al. Comparison between cylindrical and prismatic lithium-ion cell costs using a process-based cost method. February 2017. Accessed on May 21, 2025.
[36] BloombergNEF. Global Cost of Renewables to Continue Falling in 2025 as China Extends Manufacturing Lead. 06 February 2025.
[37] BloombergNEF. Global Cost of Renewables to Continue Falling in 2025 as China Extends Manufacturing Lead. 06 February 2025.

China's dominance in clean energy is because of its competitive advantage over process inputs, such as cheap electricity and access to critical minerals' supply chains. The country's average cost of electricity production is 11-64% lower than the global average (excluding China).

Other clean tech manufacturing countries may not have similar advantages. Production cost varies depending on regional factors. However, there are spillover benefits for countries that import from China. Pakistan, for instance, is the third-largest market for Chinese solar PV module exports. Due to geographical proximity and tax holidays for clean energy, solar PV module prices in Pakistan fell as low as PKR30 per watt (W) or USD0.11/W, approximating the global average production cost of USD0.10/W.[38]

Contrastingly, for BESS, various surcharges and duties have led to the average price of lithium-ion battery packs in Pakistan ranging between USD160-USD300/kWh, an addition of almost 50% of the cost.[39]

Table 9: Custom Duties and Surcharges Applicable on BESS in Pakistan

Duty Name	Applicable Rate
Customs Duty	11%
Sales Tax	18%
Regulatory Duty	5%
Income Tax	12%
Additional Customs Duty	2%
Total	48%

Source: Author analysis; Pakistan Customs.

> **"Nevertheless, driven by extremely high internal electricity costs within Pakistan and declining solar PV module costs in China, the project economics for solar + BESS installations appear to be increasingly attractive. Pakistan will likely continue with its 'solar boom', complemented by BESS for increased reliability and grid independence.**

[38] Author calculations based on market data.
[39] Author calculations based on market data.

5.1 Evaluating Battery Investment: Payback Period and Levelized Cost of Electricity

The payback period, or the time it takes for the system to recover its initial cost, is commonly used to determine whether battery storage systems are a worthwhile investment. In 2024, the warranty period for most batteries ranged from 5 to 10 years. The payback period must fall within this warranty timeframe for a battery to be considered cost-effective.

Payback periods vary significantly depending on specific use cases or applications. Factors such as residential, commercial, or industrial applications, energy consumption patterns, and local electricity costs determine a BESS project's financial viability.

This section analyses payback periods for various system sizes and use cases using simulations on PV Syst (software that simulates battery usage with solar PV systems). The system output is based on key data inputs, including electricity costs, energy usage patterns, battery efficiency, degradation rates, and solar PV integration and maintenance costs.

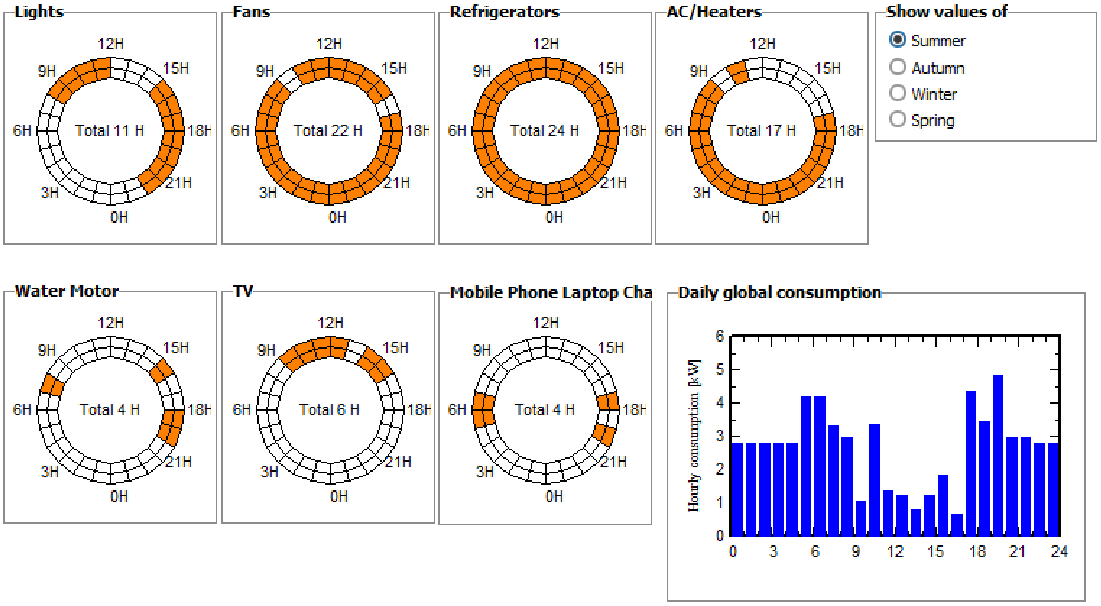
In Pakistan, BESS is mostly used with solar PV systems, with the grid serving as backup across various applications. Therefore, a similar context is assumed for the simulations. The software also calculates each system's LCOE and Internal Rate of Return (IRR) based on the inputs provided.

5.2 Residential Simulation

This simulation assumes a typical load curve of a 10kW three-phase ToU category for residential consumers. The seasonal consumption profile is provided in Section 10.2. The load is distributed across the seasons on a 24-hour daily basis according to usage variations.

A 10kW solar PV hybrid system with a 5kWh battery using bifacial solar panels to maximize energy generation is assumed to match the load curve. The system is designed based on the yield observed in the North and Central Punjab region, estimated at 4.5–5kWh per kW of installed capacity. In addition to solar PV and battery storage, the system imports energy from the grid to provide continuous power.

Figure 8: Summer Hourly Profile of a Typical 10kW Sanctioned Load Consumer



Source: PV Syst; Author analysis.

Figure 9: Daily Consumption Profile for a 10kW Sanctioned Load Consumer

Daily consumptions

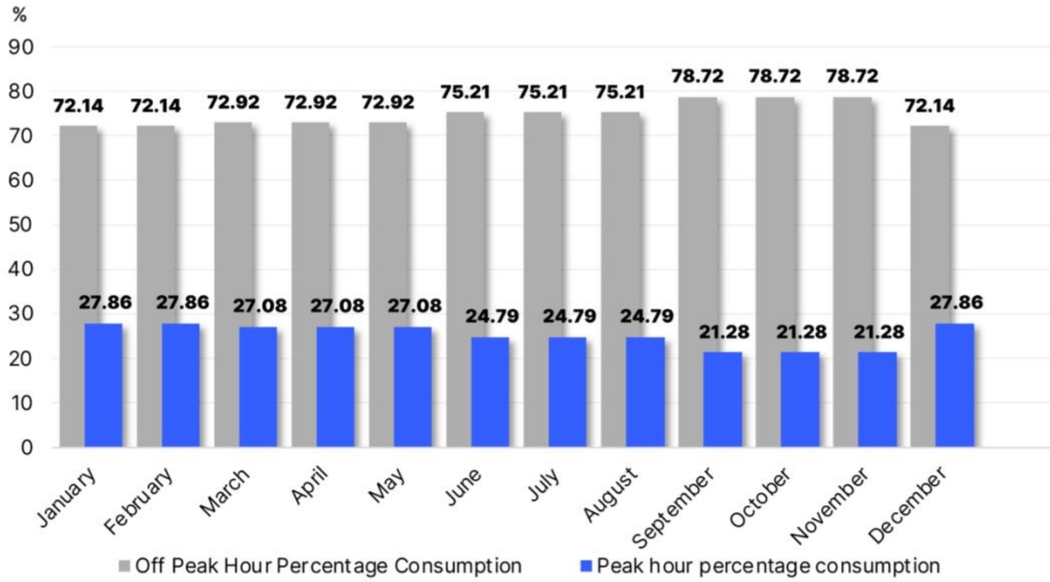
Number	Appliance	Power		Daily use		Hourly distrib.	Daily energy	
10	Lights	15	W/lamp	11.0	h/day	OK	1650	Wh
3	Fans	100	W/app	22.0	h/day	OK	6600	Wh
1	Refrigerators	500	W/app	24.0	h/day	OK	12000	Wh
2	AC/Heaters	17.00	kWh/day	17.0		OK	34000	Wh
1	Water Motor	500.0	W aver.	4.0	h/day	OK	2000	Wh
2	TV	200	W/app	6.0	h/day	OK	2400	Wh
7	Mobile Phone Laptop Charges	200	W/app	4.0	h/day	OK	5600	Wh
	Stand-by consumers	6	W tot	24 h/day			144	Wh
				Total daily energy			**64394**	**Wh/day**
				Monthly energy			**1931.8**	**kWh/mth**

Appliances info

Source: PV Syst; Author analysis.

The annual energy demand for this residential system is computed at 19.5MWh, with a 72:28 split between off-peak and peak-hour consumption.

Figure 10: Consumption Percentage for Peak and Off-Peak Hours



Source: Author analysis.

The primary use case for this arrangement is energy arbitrage, where the battery is charged using solar PV panels during daylight hours and discharged during peak tariff hours to offset high electricity costs. This approach reduces grid dependency and significantly lowers electricity bills by optimizing energy usage.

To explore scenarios where more solar PV output is used for storage and subsequent arbitrage, simulations are executed by increasing the battery size in 5kWh increments. Results are provided in Table 10.

Table 10: Results of Residential Use Case Simulations

System Size	Battery Size	LCOE (PKR/kWh)	Payback Period	Energy Supplied via Battery Storage	Total System Cost (PKR mn)
10kW	0	13.6	1.5	0	0.95
10kW	5kWh	14.5	2.7	7.6%	1.53
10kW	10kWh	18	3.3	14.9%	1.89
10kW	15kWh	21.5	4.1	21.7%	2.13
10kW	20kWh	25	5	27.8%	2.43

Source: Author analysis based on simulations run on 'PV Syst'.

A typical 10kW solar + BESS domestic installation in Pakistan is observed to have an LCOE between PKR14.5/kWh and PKR25/kWh or USD0.052/kWh and USD0.09/kWh, depending on the quantity of BESS installed.

Key Observations

i. Solar + battery systems have a lower cost per unit across all configurations than grid energy during peak and off-peak hours.

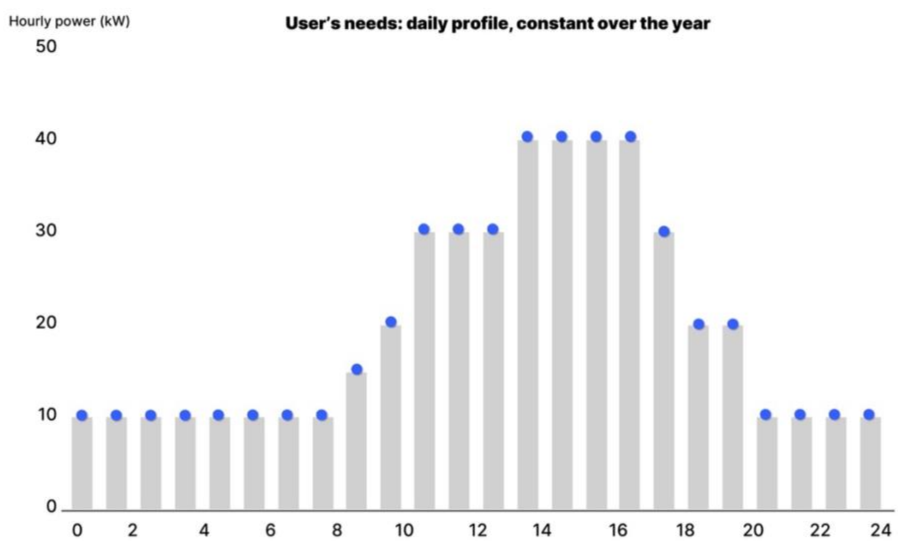
ii. Systems with batteries are particularly beneficial for peak-hour energy savings, as the grid energy price (PKR48/unit) is significantly higher. Even small batteries (such as 5kWh) can provide substantial cost savings.

iii. Due to higher capital costs, the system's LCOE increases as battery size increases, reducing the relative cost advantage over grid-based energy. The payback period remains within the 5-year benchmark. However, increasing the battery size reduces grid reliance, allowing consumers more energy independence.

5.3 Commercial Simulation

This simulation explores a typical commercial establishment where energy usage mainly occurs during office hours (9 AM to 5 PM). A sanctioned load of 50-60kW and commercial tariffs are assumed for the premises. A typical daily load profile, which peaks around 2 PM to 5 PM, is considered (Figure 11).

Figure 11: Typical Load Profile of a Commercial Establishment



Source: Author analysis using PV Syst.

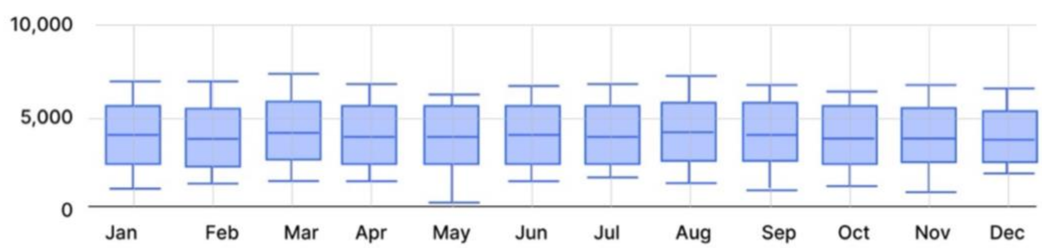
The energy demand for this setting is calculated to be 475 units (kWh) per month. Since the establishment follows business timings, most of the consumption occurs during off-peak hours, with only 20-30% occurring during peak hours. This amounts to around 70-80 units. Based on these parameters, a 100kW solar PV system with a 60kWh BESS is selected to meet the needs of a commercial establishment like this.

The investment cost of such a system is PKR13.2 million. The inflation and discount rates are presumed to be 10%. The battery replacement period is considered to be 10 years since that is what is typically offered by battery manufacturers such as Huawei and Sungrow batteries.[40] A 2% linear system degradation is also assumed. According to the simulations, such a system will directly obtain 86.2% from solar PV output, while storage would account for the remaining 13.8%. During low radiation periods, the battery can cover daytime intermittency and provide stable operations to the connected load. The payback period for this combination is 4.2 years, while the LCOE increases to PKR33.02/kWh.

5.4 Industrial Simulation

A typical industrial load of 4MW has been used for this simulation using the Homer Pro software. The load profile is continuous (a constant load of 4 MW exists 24 hours a day, regardless of the time). However, a 10% variance is included in the simulation software.

Figure 12: Seasonal Load Variation for an Industrial Consumer



Source: Author analysis using Homer Pro software.

The annual electricity requirement for such an industry is 8,760MWh. Typically, these industries have gas engines (natural gas) and a grid connection to fulfill their load demand. For this analysis, two additional sources (solar PV and a lithium-ion battery) have been added to the system to analyze the effect of grid independence using DER. Some major parameters considered for the simulations are provided in Table 11.

Table 11: Parameters for Industrial Simulation Case

Parameter	Value
Natural Gas Price	USD 0.20/m^3
Grid Price	USD 0.14/kWh
BESS Price	USD 200/kWh
Solar PV System Price	USD 500/kW

Source: Author analysis; Inputs for simulations run on Homer Pro software.

[40] Huawei. The Salient Advantages of Battery Energy Storage Systems. Accessed on 21 May 2025.

Multiple scenarios with varying shares of solar PV and BESS were created to observe how LCOE varied with a changing energy mix in an industrial setting.

a) Complete Grid- Defection - Zero Dependency on the Grid

Depending on economic viability, gaining complete independence from the grid may be desirable for industries where a reliable electric supply is crucial for operation and maintenance.

Table 12: Optimal Capacity Mix – Industrial Simulation Case

Sources	Capacity
Solar PV	3MW
Gas Gen Set	2MW
Battery	3MW
Grid	0

Energy Mix share:

Sources	Capacity	Energy (MWh)	Percentage (%)
Solar PV	3MW	9,439	45.5
Gas Gen Set	2MW	4,170	54.5
Battery	3MWh	Included in PV source	-

Source: Author analysis based on simulations run on Homer Pro software.

The benefit of such a system is that it is not dependent on the utility grid while maintaining increased utilization of solar PV resources. For autonomy and stability, a 3MWh BESS ensures the availability of adequate backup and the ability to cater for renewable energy intermittency. 70% of the load is served through renewable energy, while the remaining is provided by a gas generator (genset). Only a limited portion of the load is served through the utility network.

The LCOE for such a system is USD0.1346/kWh or PKR37.5/kWh. A payback period of 5.9 years is calculated with a 17% IRR. The total cost of the system (solar + BESS) is PKR538 million.

5.4.1 Increased renewable energy share and decarbonized energy

The following simulation case shows the total decarbonized energy share for this example. In this instance, the grid and gas genset were excluded, and only solar PV and BESS were considered energy sources.

Table 13: Energy Mix for 100% Decarbonized Power Supply in an Industrial Setting

Sources	Capacity	Energy (MWh)	Percentage (%)
Solar PV	16MW	8754	100
Battery	48MWh	Included in PV source	-

Source: Author analysis based on simulations run on Homer Pro software.

The LCOE for this system is USD0.31/kWh or PKR 86.2/kWh, significantly higher than any previous configuration due to complete grid independence. Due to the extensive amount of BESS, the capital expenditure (capex) for this system (solar + BESS) is PKR4.9 billion. However, this leads to a completely decarbonized system.

For industrial consumers, the use cases for BESS vary significantly depending on the nature of the industry. Consequently, the payback periods are not straightforward to calculate. Unlike residential or commercial settings, where battery use is often tied directly to solar storage or peak shaving, industrial applications usually involve complex operations with diverse energy demands, operational priorities, and financial metrics. These factors mean that batteries may serve multiple functions beyond simple cost savings, such as process continuity, equipment protection, and regulatory compliance in decarbonization.

For example, textile manufacturing involves energy-intensive processes such as spinning, weaving, dyeing, and finishing, which require continuous and stable power. Batteries can offer multiple benefits. First, they can reduce demand charges by shaving peaks in energy usage. Second, they prevent downtime and save valuable batches of fabric from damage. Third, they help improve power quality by reducing voltage sags or harmonics that may disrupt sensitive machinery.

Power interruptions or fluctuations in chemical plants can cause production losses and serious safety hazards. Once started, some chemical reactions must continue under controlled conditions. Any disruption can damage equipment, degrade product quality, or lead to hazardous situations. In this context, batteries are valuable for uninterruptible power supply (UPS) applications. Reliability, safety, and process continuity are critical for such an industry, often more than direct energy savings.

Batteries serve different priorities in rice mills. Many mills operate seasonally and use large motors during milling, polishing, and packaging. Diesel generators are commonly used where grid reliability is poor. Batteries can significantly offset diesel usage, leading to quicker returns. In addition, batteries allow for energy arbitrage, charging from the grid during off-peak hours or from solar, and discharging during operations, thus reducing energy bills.

Across all these sectors, the financial return on battery investment is influenced by factors such as tariff structures, diesel cost (for gensets), local grid reliability, operational hours, and renewable energy integration. Some savings, such as avoided product losses or increased operational reliability, are challenging to quantify but necessary. Therefore, a standard payback period calculation fails to capture the full value of batteries in industrial settings. Each case requires a tailored assessment to fully understand the economic and operational benefits.

6. Case Studies

By allowing increased use of self-generated electricity, battery storage systems can help consumers avail variable electricity tariffs or reduce peak electricity consumption to lower energy bills. This section provides practical case studies to assess impact.

6.1 Residential Consumer - Bilal's 10 kWh Residential BESS

Bilal resides in a 10-marla (2250sqft) house in Karachi with four family members. Consumers in Karachi are served by K-Electric, a vertically integrated private utility with its own generation, transmission, and distribution assets. Bilal's residence was prone to frequent load shedding and power outages. He opted to install a hybrid non-net-metered 7kW solar PV hybrid system with a 10kWh lithium-ion battery storage system at an average cost of PKR1.2 million.

The system was installed in September 2024, resulting in significant cost savings (Table 14).

Table 14: Bilal's 7kW/10kWh Non-Net-Metered Hybrid Solar PV System

Month	Grid-based Consumption in 2023	Grid-based Consumption in 2024	Percentage Decrease in Consumption	Approximate Savings in PKR
August	506	436	13.8	3,500
September	605	123	79.6	24,000
October	615	115	81.3	25,000
November	369	0	100	18,500
December	300	0	100	15,000

Note: Rate of energy unit is considered to be PKR50 all inclusive.
Source: Author calculations based on consumer data.

Figure 13: Bilal's Residential BESS System

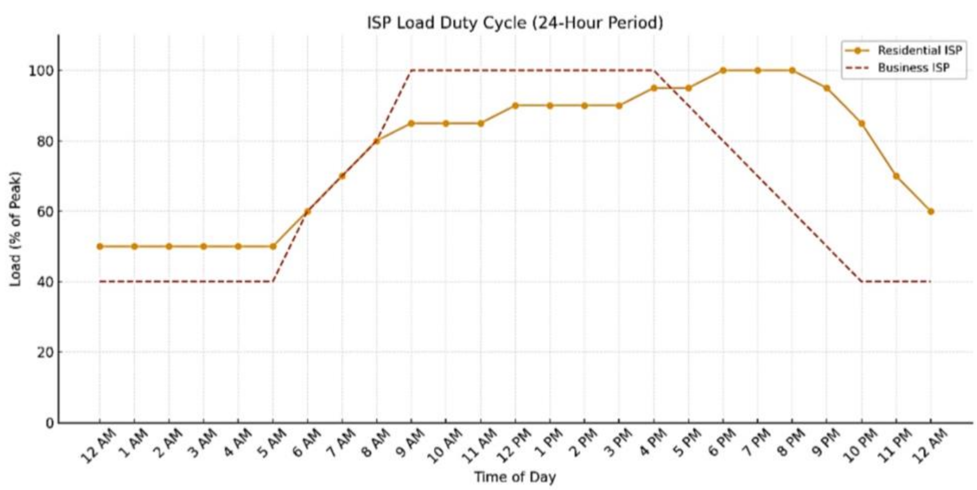
Source: Authors.

6.2 Commercial Consumer - Gem Net's 100kW/60kWh Hybrid System

Gem Net is an internet service provider (ISP) company in Hyderabad. The consumer falls in the commercial category with a sanctioned load of 100kW. Gem Net's monthly consumption rises to 12,000kWh every month, resulting in a significant energy cost of nearly PKR1 million. In addition to high energy prices, the consumer faces frequent load shedding, disrupting operations during business hours.

The load profile of an ISP depends on its client base. Energy consumption of a residential-oriented ISP peaks during grid peak hours, while that of a business-oriented provider peaks during off-peak hours from 9 AM to 5 PM. This makes it an ideal case for installing a solar PV system with BESS to reduce grid reliance and practice energy arbitrage.

Figure 14: Typical Load Duty Cycle of an ISP



Source: Author analysis using PV Syst.

Gem Net installed a 125kW solar PV system with a 100kWh BESS configuration. The system comprises four units of Sungrow's SBH series 15 kWh lithium-ion battery packs. A 100kW solar PV system with four 25kW inverters is also installed for solar power generation.

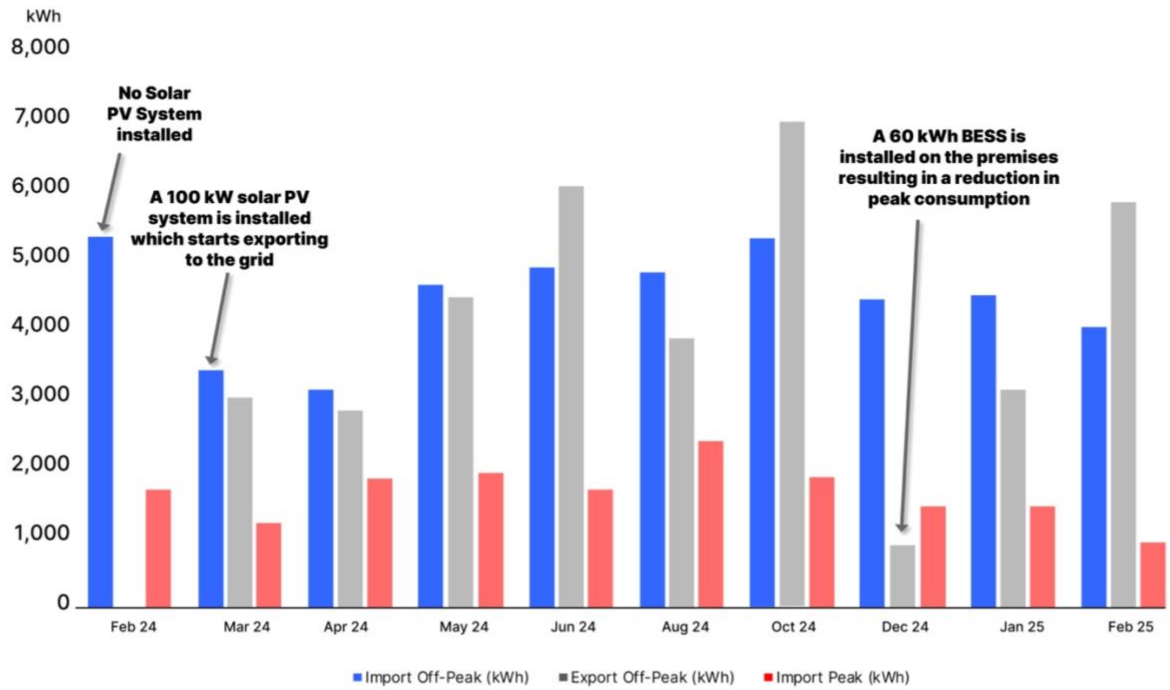
This system offers significant benefits, including substantial savings on electricity bills, relief from peak-hour consumption costs, and a reliable solution to eliminate load-shedding issues.

Figure 15: Gem Net 100kW/60kWh Hybrid System

Source: Gem Net.

Figure 16 demonstrates how the facility's peak consumption dropped to almost 50% of the previous year after adding battery storage.

Figure 16: Changes in Peak Consumption after Installation of Solar + BESS at Gem Net



Source: Author analysis based on primary energy consumption data from Gem Net.

6.3 Industrial Consumer - Liberty Textile Industry's 4MWh Battery Storage System

Liberty Textile Mills Limited (LML) is a prominent textile manufacturing company in Pakistan, known for its high-quality fabric production and innovation.

LML installed a 4MWh/4MWp BESS system, the country's first microgrid, powered by renewable and conventional sources. LML has 9MW wind and 7.5MW solar capacity, including fixed-tilt roof-mounted and single-axis tracker-based ground-mounted system with bi-facial panels. Conventionally, LML has four gas gensets with a combined capacity of 11MW. To stabilize this mix of generation assets, Huawei's 4MW/4MWH 1C BESS has been installed, which operates in both grid-forming and grid-following modes with seamless switching during operation.

The reasons for LML's implementation of this state-of-the-art microgrid using BESS include:

a. Maximizing operations on renewable power
b. Reducing running costs
c. Renewable energy integration
d. Avoiding power curtailment when excess energy is available
e. Preventing critical equipment downtime due to fluctuations in gas pressure
f. Avoiding load shedding while on Hyderabad Electric Supply Company's (HESCO) grid
g. Reducing the carbon footprint

When the gas gensets, the primary power sources, experience a drop in gas pressure and are about to trip, the BESS converts to grid-forming mode. All other sources are synced to it, allowing LML to shut down some of the gensets to maintain power on the remaining generators.

Figure 17: Mini-grid at LML

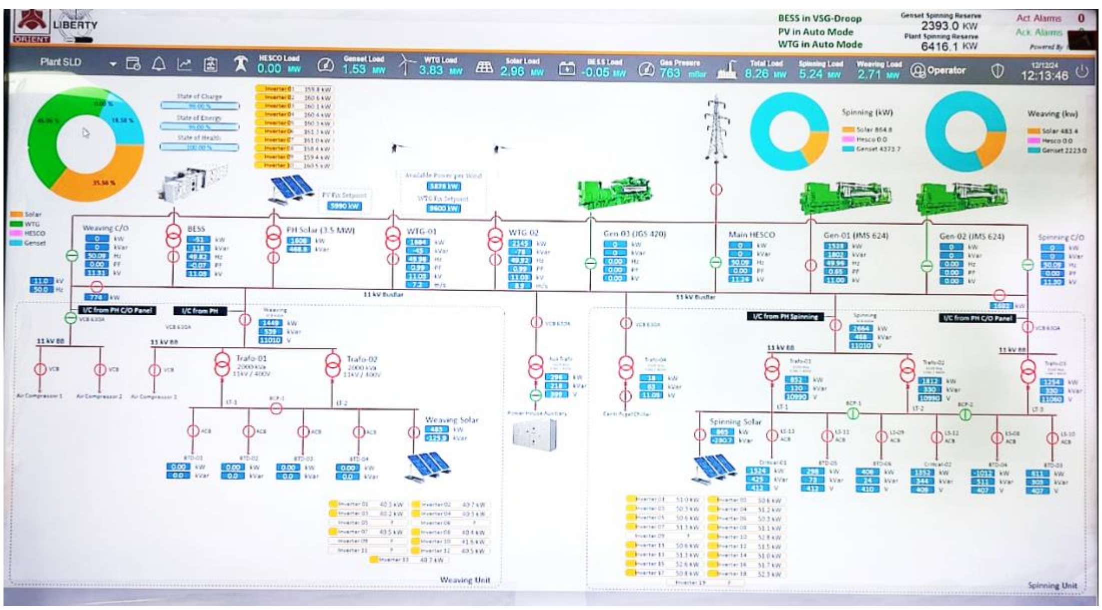
Source: Liberty Textile Mills.

Figure 18: BESS with Power Conversion System (PCS)

Source: Liberty Textile Mills.

The load is operated through clean, renewable energy sources, and intermittency is catered for. Consequently, LML has significantly reduced its reliance on grid-based power and has shut down a 4MW gas genset due to the availability of stable renewable energy from its diverse portfolio.

Figure 19: EMS System Dashboard at LML



Source: Liberty Textile Mills.

7. Demand Defection and Grid-related Challenges

Favorable economics and the potential for energy independence have led both net-metered and non-net-metered solar PV[41] systems to reduce grid demand by nearly 10 terawatt-hours (TWh). This growing shift threatens the stability of physical distribution infrastructure in areas with high solar PV penetration. At a broader level, falling demand has led to financial losses for utilities and increased capacity payments for the government and remaining consumers.

The government attempted a two-pronged approach to mitigate the situation and increase power consumption from the central grid. A 'winter package'[42] was offered to all consumer categories from December 2024 to February 2025, where a PKR26.07 per kWh concessional rate for incremental consumption above a designated threshold was allowed.[43] Conversely, NEPRA imposed increased fixed charges across all consumer types from July 2024. The government also announced the disconnection of gas supply to captive power plants from January 2025, but technical constraints and industry opposition prevented full-scale implementation. Meanwhile, the government has increased gas prices for captive power plants[44] to discourage gas usage and encourage a shift to the national grid.

While understandable, these policies create regulatory uncertainty and may give further incentive to reduce reliance on the grid by installing alternate energy sources and BESS on-site. As demonstrated by the BESS case studies in the previous section, the idea is already gaining traction.

BESS adoption may also attract consumers as the government considers imposing higher fixed charges[45] for net-metered consumers and addressing gaps in the existing Net Metering Policy. For instance, the current method of crediting excess production by net-metered solar systems has resulted in some consumers achieving zero electricity bills, causing the government to lose taxation revenue.

Therefore, Pakistan's Federal Tax Ombudsman (FTO) directed power distribution companies (DISCOs) to charge an 18% sales tax on the gross value of electricity supplied to net-metered solar consumers, regardless of any energy fed back to the grid and the subsequent 'netting off' of electricity units. A similar ruling would also apply to withholding income tax, which must also be deducted from the gross amount of electricity consumed.

High prevailing electricity tariffs and the imposition of sales and income taxes can significantly increase the gross value of electricity consumed and pose a substantial long-term financial burden

[41] Off-grid and behind-the-meter (BTM) large-scale establishments.
[42] Business Recorder. 'Winter package': Nepra approves Rs26.07 per unit relief for 3 months. 07 December 2024.
[43] The benchmark consumption would be higher than the relevant month's consumption in FY2024 or the historical consumption over the past three years for the relevant months, based on a NEPRA-approved formula.
[44] Profit. SNGPL raises concerns over gas supply shift from captive power plants. 03 February 2025.
[45] Business Recorder. Fixed charges: boon or bane for electricity consumers?. 24 June 2024.

on consumers. Such a situation would improve BESS project economics even more, driving increasing numbers of consumers away from the grid.

7.1 Scenarios for Grid Defection

Grid defection could occur across multiple sectors in Pakistan. Residential, industrial, and commercial net-metered consumers, anticipating net metering regulation and billing changes, may invest in BESS, supported by improving economics and projected declines in lithium-ion battery prices.

LCOEs for residential cases provide a clear motivation for BESS installation and independence from the grid. Table 15 shows that for a 10kW system, the highest volume of BESS addition (20kWh) will result in LCOEs that are at least 40-48% lower than the grid's peak and off-peak electricity rates.

Table 15: Levels of Grid Defection for a 10kW Residential Solar PV System with Varying Volumes of Battery Storage

System Size	Battery Size (kWh)	Dependency on Grid	Grid Defection (kWh)	LCOE (PKR/kWh)	Lower than Peak Rate	Lower than Off-Peak
10kW	0	Maximum	Minimal	13.6	70%+	65%+
	5	Considerable	1482	14.5	70%	65%
	10	Considerable	2906	18	62.5%	57%
	15	Low	4232	21.5	55%	49%
	20	Minimum	5421	25	48%	40%

Source: Author analysis.

Adoption of BESS by Net-metered Consumers

After investing in a rooftop solar PV system, the next step for net-metered consumers is to install battery storage. This becomes more attractive as the government considers tightening net metering regulations, including reducing buyback rates and limiting system sizes.[46] It is estimated that net-metered connections continue to increase at 300MW[47] per month. The total capacity of net-metered solar PV installations was 4.1GW at the end of January 2025.

[46] Profit. Govt mulls lower solar net metering rates, shares plan with IMF officials. 07 March 2025.
[47] Author analysis based on data obtained from DISCOs.

> **"If all existing net metering capacity were paired with equal-sized battery storage systems[48], it could reduce annual electricity demand from the grid by 1.5 terawatt-hours (TWh) or 1.1% of the country's electricity demand in 2024.**

This shift may happen incrementally, with only a small portion switching to BESS immediately.

Table 16: Scenarios for Adoption of BESS by Net-metered Solar PV Capacity in Pakistan

% of 4.1GW net-metered capacity	BESS Installed (GWh)	Grid Defection (GWh)
25% BESS adoption (GWh)	1.03	374.125
50% BESS adoption (GWh)	2.05	748.25
75% BESS adoption (GWh)	3.08	1122.375
100% BESS adoption (GWh)	4.10	1496.5

Note: Calculations are based on a daily charging and discharging cycle, where the battery energy storage system is charged through solar output.
Source: Author calculations.

Adoption of BESS by Off-grid and On-grid Solar PV Installations

Net-metered solar installations represent only a small portion of the country's total solar PV imports. As net-metered systems are capped at a maximum of 1MW, a large portion of Pakistan's solar PV imports exists in off-grid and non-net-metered installations in the agricultural, commercial, and industrial sectors. An estimated 11.5GW of non-net-metered and off-grid solar PV capacity is used by larger commercial and industrial establishments, agricultural tubewells, non-net-metered residential installations, and subsidized provincial solarization schemes for low-income households (Table 17).

[48] For instance, a 10kW net metered solar PV installation, puts up a 10kWh lithium-ion battery pack.

Table 17: Categories and Quantity of Distributed Solar PV Installations in Pakistan

Type of Installation	Net-metered	Grid Connected	Energy Feedback to the Grid	Installed Capacity (GW)	Contribution Towards Reduction in Grid Demand (TWh)
All kinds domestic of net-metered solar	Yes	Yes	Yes	2.05	2.9
Non-net-metered residential or other types of solar (provincial programs)	No	Yes	No	1.5	1.6
Commercial and Industrial (C&I) solar*	Yes	Yes	Yes	2.0	2.1
	No	Yes	No	3	3.7
Off-grid solar	No	No	No	0.5	N/A
Agriculture tubewell solarization	No	No	No	5	N/A
	No	Yes	No	1.45	1.8
	Yes	Yes	Yes	0.05	0.1
Total				**15.55**	**12.1**

Note: Large scale C&I solar PV installations without energy feedback can be categorized as captive solar plants.
Source: Author analysis based on information from the DISCOs.

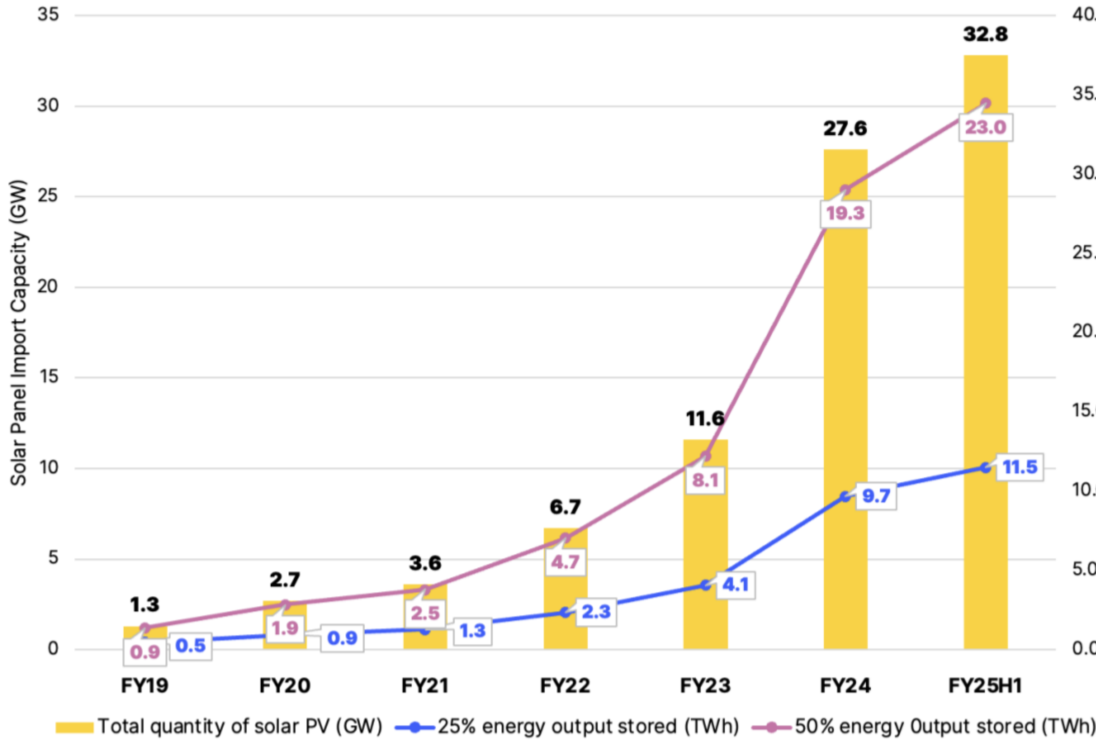
Pakistan imported 27.6GW of solar PV modules between FY2019 and FY2024[49], while another 5.2GW was brought in during the first six months of FY2025.[50] Half of the total imported capacity is currently installed across the country.

The current high upfront cost of battery storage systems in Pakistan is likely to prevent all rooftop solar and captive solar consumers from adopting battery configurations. Additionally, consumers may require multiple battery packs to end grid dependence during the night. Assuming that the batteries are charged by solar, some categories, such as single-phase consumers with smaller households, may not have the additional rooftop space required to charge BESS.

Similarly, commercial enterprises such as offices that only operate between 9 AM and 5 PM may not need BESS at night. Therefore, a conservative estimate, where only 25% of the solar panel's energy output gets stored in batteries, shows that there could be an 11.5TWh of permanent reduction in grid demand annually.

[49] Renewables First. The Great Solar Rush in Pakistan. 2024.
[50] Renewables First. The Great Solar Rush in Pakistan, The Momentum Continues. January 2025.

Figure 20: Scenarios for BESS Adoption Based on Total Solar PV Imports



Source: Author Analysis; Renewables First.[51]

Due to the modular nature of battery energy storage systems, permanent demand reduction is a concerning long-term trend. Total electricity demand for Pakistan's national grid and K-Electric was 137TWh cumulatively for FY2024.[52] An 11.5TWh decrease in grid demand represents almost 8.4% of this total. Energy consumption from the national grid has already been on the decline, with the country experiencing an 11% fall in energy generated between FY2022 and FY2024.[53] This is despite the addition of almost 3.7 million new consumers to the distribution networks of the national grid and K-Electric.

According to NEPRA, there are various reasons for declining grid demand. The most significant reductions were observed in the industrial and agricultural consumer categories, attributable to the high cost of grid-based electricity. Other reasons include poor performance by the DISCOs and high system losses. The rise in distributed generation, and rooftop solar PV installations, in particular, reflects declining public confidence in the centralized power system as unresolved issues persist.[54]

As battery storage solutions become more viable, concerns are rising that grid demand may continue shrinking if the national grid cannot deliver affordable and reliable electricity. Growing

[51] Renewables First. The Great Solar Rush in Pakistan: Keeping the momentum. 30 January 2025.
[52] NEPRA. State of the Industry Report 2024. Accessed on 28 April 2025.
[53] NEPRA. State of the Industry Report 2023. Accessed on 28 April 2025.
[54] NEPRA. State of the Industry Report 2024. Accessed on 28 April 2025.

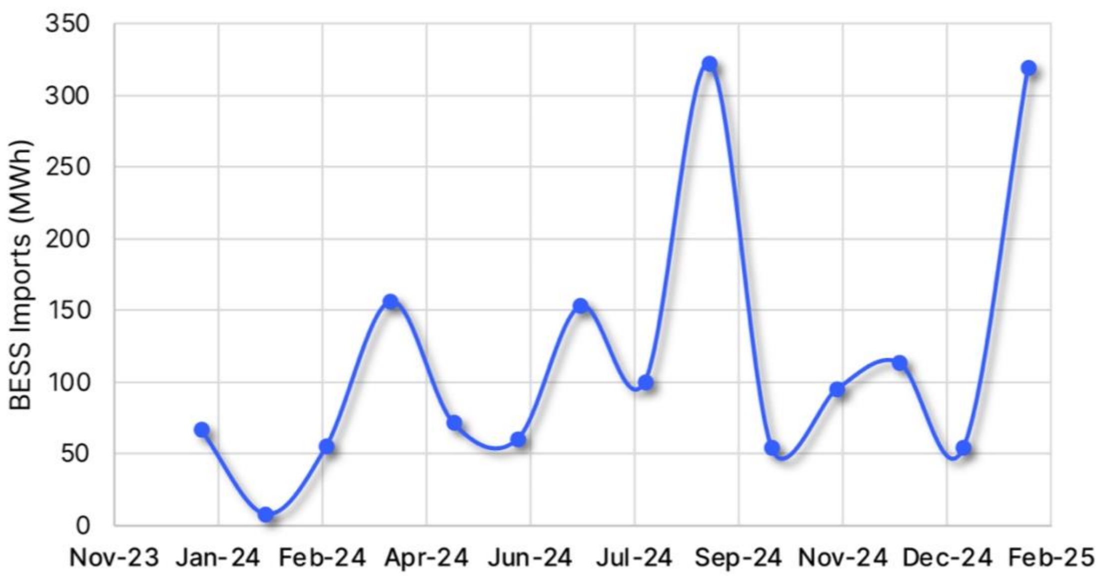
battery storage adoption also increases the risk of asset stranding and underutilization of thermal assets unless effective countermeasures are implemented.

A comprehensive, multi-pronged approach is needed to curtail the exit of consumers from the grid. This may include measures to retain existing consumers and create new demand through efficient tariff structures, infrastructure improvement, improved governance, and enhanced system efficiency.

Energy Demand Reduction Based on BESS Imports

Another way of assessing BESS adoption levels is by examining lithium-ion battery storage imports. According to analysis by IEEFA, approximately 1.25GWh of lithium-ion battery storage packs were imported to Pakistan between January and December 2024. This accounts for around 4.7% of the 25.6 GW[55] annual peak demand in 2024. Based on a daily charging-discharging cycle, installing the 1.25GWh imports could mean a yearly deduction of 438GWh of demand from the grid.

Figure 21: Lithium-ion Battery Storage Imports in Pakistan (2024-2025)



Source: Author analysis based on Customs data.

While not immediately alarming, this trend could accelerate if it follows the exponential growth of solar PV imports in Pakistan. As a result, financial losses and technical challenges for the country's central grid could amplify.

Pakistan has a surplus of installed generation capacity, which often remains underutilized. Power generation expansion planning aims to meet the peak demand experienced by the power sector for

55 NEPRA. State of the Industry Report 2024. Accessed on 28 April 2025.

only a few hours annually. The capacity contracted is for a long-term basis, with fixed capacity payments, regardless of actual plant utilization.

This has led to overcapacity and economic inefficiency in the national grid, increasing consumer tariffs. For instance, in June 2024, the national grid had an installed generation capacity of 42.5GW, while the system experienced a maximum and minimum recorded demand of just 30GW and 7GW, respectively. Due to transmission constraints, the grid could only serve a peak demand of 25.6GW. Overall, the average annual load served by the system was 18.5GW, indicating a case of substantial underutilization of generation assets.

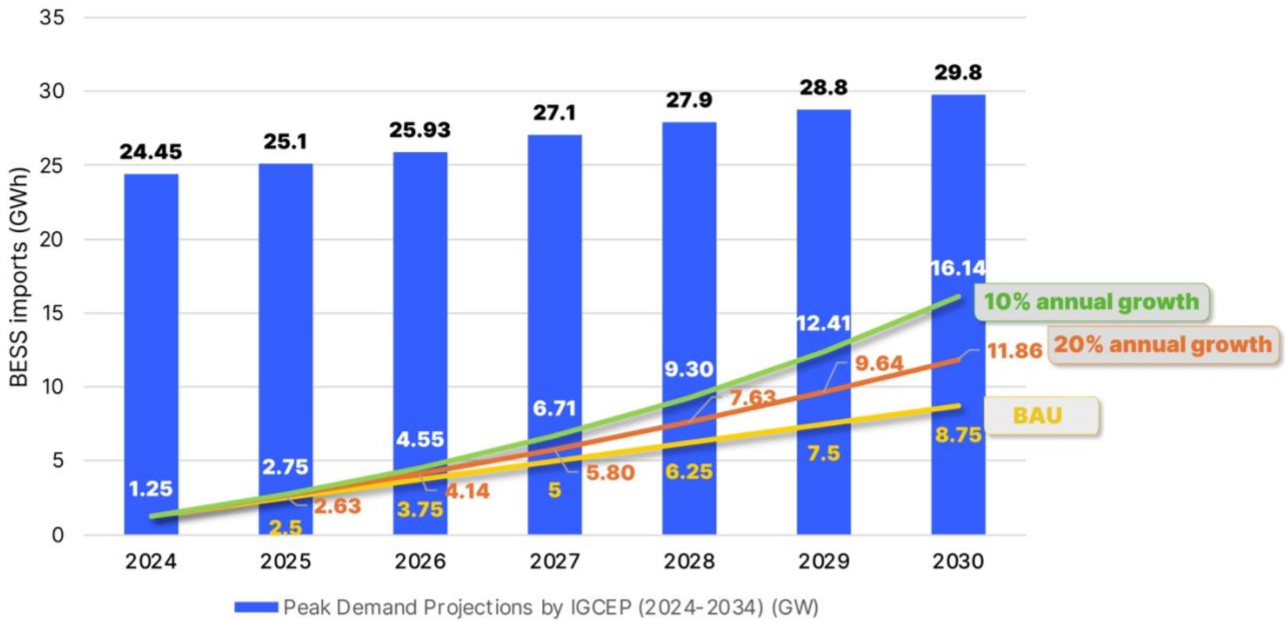
The growing trend of solar PV capacity is projected to have already resulted in an almost 10-12TWh of demand reduction from the grid (Table 17). According to the government's estimates, net-metered solar PV capacity alone led to an excess of PKR159 billion in grid storage costs and capacity payments, which consumers bore through a PKR1.5/kWh tariff hike in 2024.[56] This is being referred to as an 'existential crisis' for Pakistan's utilities or a 'death-spiral', where the rising number of rooftop solar PV installations, lower revenue creation for utilities, leading to fewer customers bearing the increasing burden of maintaining the grid.[57]

BESS imports are likely to increase. Consumers are expected to discharge their batteries during peak hours, reducing peak demand gradually. This could lead to underutilization of expensive LNG-based peaking plants, which are locked into the grid for at least the next 23-28 years[58], exacerbating the current surplus LNG dilemma. Pakistan had to defer its LNG agreement with Qatar for 2025 and delay deliveries till 2026 due to low utilization of LNG-based power plants, the main off-taker for contracted LNG.[59]

IEEFA estimates that BESS imports could reach 8.75GWh by 2030 if business as usual persists and the annual addition of BESS remains at 1.25GWh (Figure 22).

[56] The News. Roof solar net metering shifts Rs159bn burden on grid consumers. 09 March 2025.
[57] Profit. The double whammy of declining electricity demand and increased consumer tariffs. 29 July 2024.
[58] The oldest LNG-based plant in Pakistan, Haveli Bahadur Shah Power Plant, is 7 years old, while the youngest, Trimmu LNG plant is only 2 years old. The plants have been contracted for a lifetime of 30 years.
[59] Reuters. Pakistan's LNG deal with Qatar open to renegotiation next year. 07 February 2025.

Figure 22: Projections for Battery Imports in Pakistan (2025-2030)



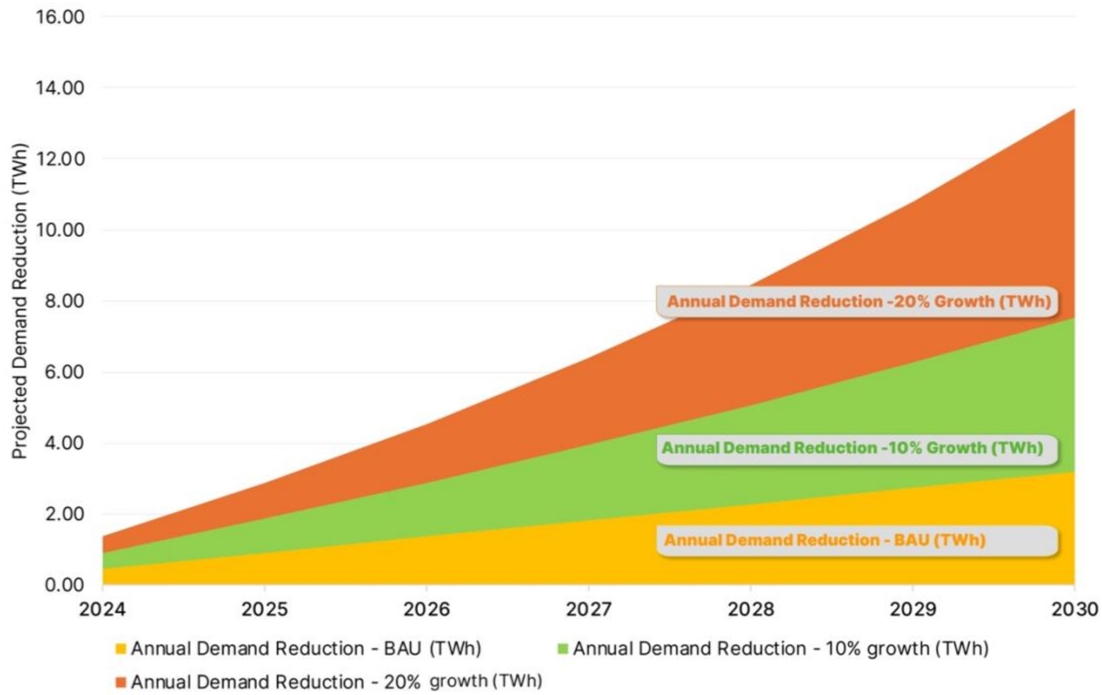
Source: Author analysis.

Based on a daily charging and discharging cycle, 8.75GWh of installed BESS capacity could mean an annual grid defection of 3.2TWh by 2030. This may increase to 5.9TWh if more aggressive growth rates for BESS are considered. This represents a 2.3-4.3% contraction in the current levels of grid-based demand.

> **8.75GWh represents 26% of the National Transmission and Despatch Company's (NTDC) projected peak demand of 34GW in 2030. A nearly one-quarter permanent reduction in peak demand could pose challenges for the regulator, utilities, and grid planners unless BESS is integrated to support the grid.[60]**

[60] NEPRA. State of the Industry Report 2024.

Figure 23: Annual Grid Defection Based on Projected Battery Imports in Pakistan (2025-2030)



Source: Author analysis.

The grid should adapt to changing consumer dynamics and increasing adoption of alternative energy sources. BESS has inherent peak shaving abilities, which could work to the grid's advantage and result in cost savings by reducing centralized generation. As more distributed solar systems operate, the grid is already experiencing peak-demand shifting. Consumers with solar PV installations defect from the grid during the day but reappear during the night, leading to declining minimum demand during the day but a rising peak demand during the evening (known as the duck curve).[61] Daytime demand is expected to decrease even further if rapid solarization continues, which may jeopardize system stability. Instances of extremely low demand, such as during holidays, may cause utilities to trip, leading to the risk of grid failure. Conversely, the surge in evening peak requires a quick ramp-up of fossil fuel-based power generation.

BESS can help smooth out these discrepancies (flattening the duck curve) by storing excess energy production during the day and dispatching it during the evening peak hours.

The problem of capacity payments due to surplus grid capacity may persist unless contracts are shifted to a 'take and pay' basis, where utilities only pay for actual energy purchased from plants.

[61] The duck curve represents the mismatch between solar energy generation and electricity demand. Solar power peaks during the afternoon, while demand typically surges in the evening as the sun sets. This creates a steep ramp-up in energy needs during the evening hours.

8. Policy Recommendations

The IEA predicts global battery storage capacity to increase nine to fourteenfold by 2030, rising from just 86GW in 2023 to between 760GW and 1,200GW by 2030, depending on the volume of renewable energy additions. While advanced economies like the United States, China, and the European Union have led battery storage adoption, emerging economies are not far behind. Pakistan, for instance, is experiencing a solar revolution with almost 17GW of solar capacity at the distributed and utility level, quickly catching up with the United Kingdom, Poland, and Vietnam. Pakistan's adoption of BESS is also expected to grow, especially in decentralized, behind-the-meter (BTM) settings. While positive for the advancement of the country's clean energy goals, this transition should occur strategically, without placing the grid in a 'utility death spiral', as predicted by many.[62] Grid planners and policymakers need to keep the grid afloat while managing the addition of more distributed solar and battery storage. Several strategic, regulatory, and technical steps will be required to achieve these goals.

Improve distribution system planning process (Bottom-up approach using advanced predictive techniques)

Modern distribution system planning requires accurate medium-term load forecasting. These projections allow power distribution companies, regulators, and stakeholders to anticipate electricity demand over a multi-year horizon. This is essential for making informed decisions about power procurement, generation expansion, infrastructure investments, and regulatory interventions. Traditionally, load forecasting was conducted at a macro level. However, the energy landscape has evolved significantly with the increasing penetration of DERs such as rooftop solar PV systems, BESS, and electric vehicles.

In this changing context, a revamped, decentralized planning approach is needed. A feeder-wise, bottom-up load forecasting methodology could be adopted to accurately reflect localized demand dynamics. This method allows for granular insight into consumption patterns, the impact of DERs, and local constraints, which are often overlooked in top-down forecasting methods.

This bottom-up approach could be further enhanced by integrating weather forecasts, which directly influence cooling and heating loads, especially in climate-sensitive regions. Including macroeconomic indicators such as Gross Domestic Product (GDP) growth rates, industrial output, urbanization trends, and interest rates can also improve the robustness of demand projections. These variables impact residential and industrial electricity consumption, and their predictive value is essential for aligning planning with broader economic trends.

By forecasting load growth at the feeder stage, utilities can aggregate this data with far greater accuracy up to the substation, zone, and system levels. This leads to a more realistic estimation of

[62] PV Tech. Disco death spiral looms amid Pakistan's 'perfect storm' of rooftop solar domination. 31 January 2025.

future capacity requirements, helping to avoid the pitfalls of over-procurement or underutilized infrastructure investments. It also supports more effective policy development that aligns with actual demand patterns and consumer-distributed resource deployment.

Strategic addition of centralized generation capacity

Pakistan is struggling to manage rapid solarization amid an oversupply of generation capacity. This situation could worsen with the added adoption of battery storage systems. Therefore, the government may have to stall any new utility level capacity additions temporarily while carefully assessing the improving economics of solar + BESS across the region.[63] The recently finalized Indicative Generation Capacity Expansion Plan (IGCEP) 2025-2034 excludes projects with a capacity above 7,000MW due to a lower demand forecast, attributed to distributed energy resources.

Adopting the correct regulatory framework to optimize BESS addition

The grid's flexibility requirements increase as energy supply and demand change in Pakistan. These variations are due to variable generation from solar and wind resources and energy feedback from net-metered distributed solar systems. A strong regulatory framework is needed to support the transition. NEPRA's grid code, which was updated in 2023, applies mainly to the transmission system. As DERs are primarily integrated at the distribution level, their successful induction requires conducting hosting capacity analysis for short- and long-term adoption. Therefore, the distribution code (which is separate from the transmission network) for Pakistan and only incorporates the distribution system) needs to be updated, and modern control and monitoring mechanisms must be made mandatory for the system operator.

Advanced forecasting and locational value analysis are also important to understand the potential of generation, capacity, frequency response, and ramping services that DERs can provide at a specific location on the distribution system. The grid/distribution code must support DER monitoring and control activities, including observing the distribution grid. Parameters such as factors affecting performance and the ability to control and adjust DER output should be accounted for.

Additionally, the grid code must also call for timely engineering studies for interconnection and operation of distributed resources in parallel to the central grid.[64]

BESS is critical for ancillary services in other countries due to its quick energy dispatch and voltage support capabilities. As renewable energy adoption increases in Pakistan, the need for ancillary services regulation becomes inevitable.

[63] Dawn. Govt scraps 10,000MW projects to curb costs. 10 January 2025.
[64] US Department of Energy. Distribution Grid Code Adoption Pathways. June 2024.

Grid modernization and digitization to support renewable energy and battery storage integration

The diverse location of DER and energy feedback from the rapid influx of rooftop solar PV across major load centers in Pakistan is leading to issues such as reverse power flow and negative loading on distribution transformers in feeders. Concurrently, there is little visibility and control across power sector communication networks, which leads to slow response and restoration activities in case of issues. Resolving these challenges requires modifying grid infrastructure, including the widespread adoption of smart meters, consumer and transformer monitoring systems (asset performance management), and feeder-level automation and modernization. Distribution utilities could then monitor power flows from distributed resources and develop an effective control strategy during surplus and deficit grid supply.

A cohesive Information and Communications Technology (ICT) strategy is also needed to transmit collected data to control centers and enhance existing communication networks by augmenting current systems with radio frequencies, long-range wide-area networks, and optical fibers. Pairing these data management technologies with data analytics services and a distributed energy resources management system (DERMS) can allow DISCOs to effectively manage a grid with a high DER volume. A supervisory control and data acquisition (SCADA) system should also be incorporated into all major distribution control centers for the DERMS to offer the highest functionality.[65]

Once such systems are implemented, the offtake of DER can be high without risking grid stability.

Maximizing benefits from BESS - Aggregating DER into virtual power plants

In terms of functionality, BTM battery storage deployment at an individual household or commercial level can provide the same benefits as utility-scale battery storage. Individual household battery systems can be aggregated into virtual power plants (VPPs), allowing participation in electricity markets. In addition to cost savings at the grid and consumer levels, these BTM systems can provide essential grid-firming services, such as improving system reliability during unplanned outages through power backup. This is important for critical industries and hospitals that require an uninterruptible power supply.

Aggregated solar + BESS virtual power plants can also reduce overall grid demand and stress by shaving peak demand and providing reserve capacity during congestion.

On a localized level, BESS, in combination with distributed solar systems, can create opportunities to defer distribution grid expansion or upgrades, reducing maintenance expenses for distribution

[65] Next Krafftwerke. What is DERMS?.

utilities. On an aggregated level, VPPs can benefit ancillary services like voltage support, reactive power compensation, and frequency regulation. However, these advantages depend on the level of grid modernization and smart metering deployment that Pakistan can implement. Regulatory frameworks addressing market access and end-user tariff structures are essential for efficient BESS utilization in Pakistan. These should provide fair compensation for grid services (such as export rates for peak hours and reactive power compensation) by individual BESS and DER installations.

9. Conclusion

Battery energy storage systems are rapidly becoming a cornerstone of modern energy infrastructure, offering significant benefits for residential, commercial, and industrial sectors. Advantages range from peak load reduction and energy cost savings to improved reliability and power quality. With global prices of battery systems on a downward trend, adoption is accelerating worldwide, and Pakistan is no exception, as evidenced by increasing BESS imports. This momentum reflects an increasing recognition of battery energy storage as a key enabler of energy independence and resilience.

Pakistan's federal government, through the Ministry of Energy, is taking proactive steps to ensure that future power procurement strategies are aligned with evolving demand patterns. As rooftop solar PV adoption increases, potentially accelerated by anticipated changes in the net metering policy, there is a growing shift towards integrating BESS. These hybrid systems (solar + BESS) aim to enhance self-consumption and reduce grid reliance. Federal-level procurement planning is being approached with greater caution, aiming to avoid over-contracting, resulting from demand reductions and DER.

The rise of distributed storage and prosumer activity underscores the urgent need for revamped distribution system planning and grid modernization. Distribution system operators should have advanced monitoring, control, and forecasting capabilities to manage increased BESS and distributed solar adoption. Using an innovative approach, Pakistan can create a more adaptable, efficient, and secure electricity network that supports consumer choice and system reliability in a rapidly evolving energy landscape.

Technical grid characteristics and the regulatory framework available are crucial factors in determining the right use case for batteries. Pakistan's high penetration of rooftop solar generation can provide a strong foundation for large-scale battery storage adoption in a distributed manner.

Improving project economics has resulted in a strong localized push for DER adoption despite high duties and surcharges. The government may require minimal investment for new generation assets if sustained through fiscal and regulatory incentives.

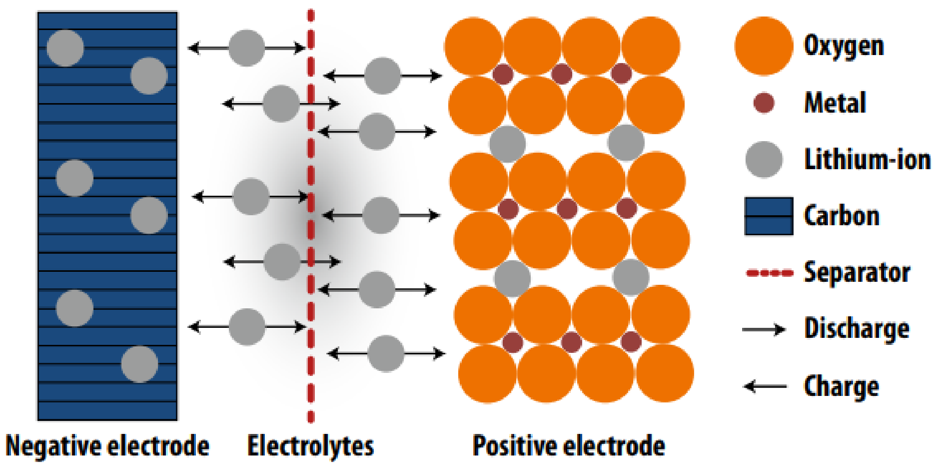
However, a lack of grid modernization and strong regulatory support remain key barriers that should be addressed to ensure Pakistan's energy transition happens strategically without jeopardizing the future of the national grid.

10. Appendix

10.1 Lithium-ion Batteries in the Pakistan Market

Batteries store and release energy through an electrochemical reaction involving the cathode (positive electrode) and the anode (negative electrode). During this process, electrons flow from the anode to the cathode, converting chemical energy into electrical energy. Lithium-ion batteries are the most common type of battery used for energy storage after lead-acid batteries. Lithium ions move between the anode and cathode in lithium-ion batteries, facilitating this energy conversion.

Figure 24: Chemical Flow of Lithium-ion Battery



Source: IRENA.[66]

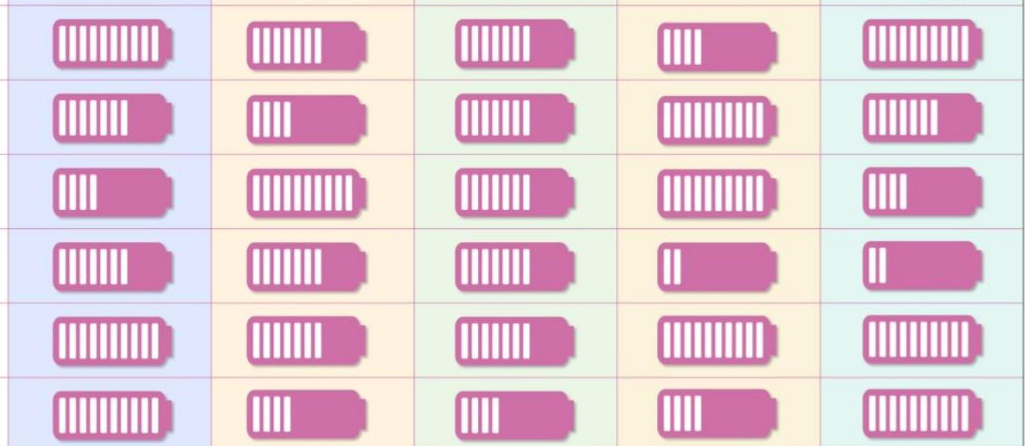
In most lithium-ion batteries, the anode is composed of a lithium graphite compound. The electrolyte, which allows lithium ions to move between the negatively charged anode and the positively charged cathode, is an organic solvent containing lithium salt.

The materials used for the electrodes can vary widely, resulting in different types of lithium-ion batteries. These variations influence key characteristics such as cost, performance, specific energy, specific power, lifespan, and safety, leading to various options for diverse applications.

[66] IRENA. Electricity Storage And Renewables: Costs and Markets To 2030. October 2017. Page 64.

Figure 25: Characteristics of Various Lithium-ion Batteries

Key Active Material	Lithium-Iron Phosphate	Lithium Nickel Manganese Cobalt Oxide	Lithium Manganese Oxide	Lithium Nickel Cobalt Aluminum	Lithium Titanate
Technology Short Name	LFP	NMC	LMO	NCA	LTO
Cathode	LiFeP04	$LiNi_xMn_yCo_{1xy}0_2$	$LiMn_2O_4$(Spinel)	$LiNiCoAlO_2$	variable
Anode	C (graphite)	C (graphite)	C (graphite)	C (graphite)	$Li4Ti_5O_{12}$
Safety					
Power Density					
Energy Density					
Cell Costs Advantage					
Lifetime					
BESS Performance					



Source: Electricity Storage And Renewables: Costs and Markets To 2030, IRENA.[67]

Lithium-ion batteries have emerged as the cornerstone of energy storage solutions across residential, commercial, and industrial sectors. Their high energy density, efficiency, and scalability make them the preferred choice for various use cases, from backup power to renewable energy integration. Lithium-ion batteries are versatile energy storage technologies that scale seamlessly from portable applications to large-scale industrial systems. Understanding the progression from individual cells to complex energy storage systems provides insight into their widespread applicability across residential, commercial, and industrial sectors.

10.1.1 From Cells to Containerized Solutions

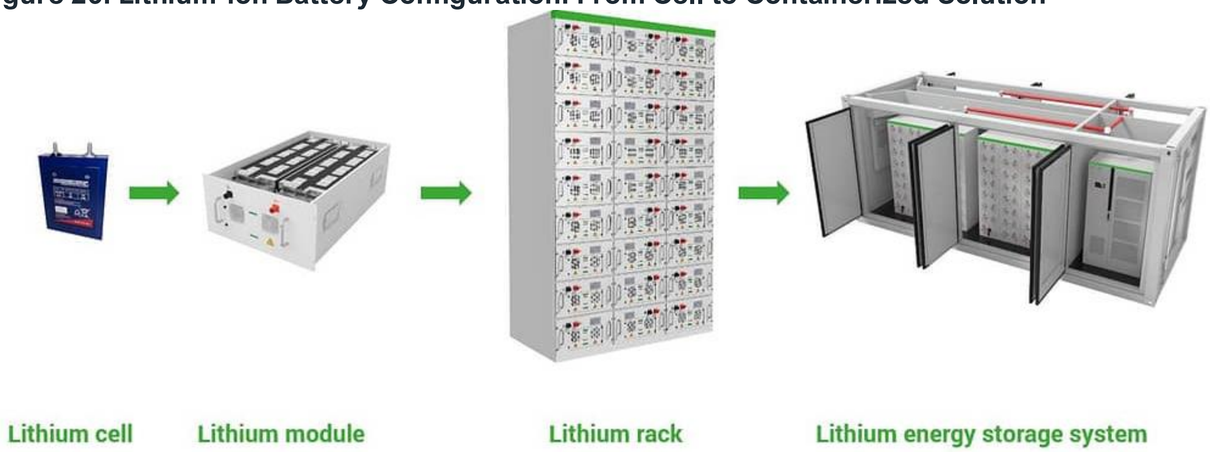
A lithium-ion cell is the smallest functional unit of a battery system, designed for on-the-go applications requiring portability, lightweight, and high energy density. These cells are used in mobile phones, laptops, and power tools, where compactness and rechargeability are critical. Typically, they are rated at 3.6 to 3.7 volts (V), with capacities ranging from 1 ampere-hour (Ah) to 5Ah per cell.

Individual cells are combined to form battery packs (modules) to deliver higher voltage, current, and capacity suitable for larger applications. Cells are arranged in series to increase voltage and in

[67] IRENA. Electricity Storage And Renewables: Costs and Markets To 2030. October 2017. Page 65.

parallel to increase capacity, along with Battery Management Systems (BMS) for safety and efficiency. These packs or modules are commonly used in residential applications.

Figure 26: Lithium-ion Battery Configuration: From Cell to Containerized Solution



Source: Author Analysis based on various sources.

For commercial applications, multiple battery packs are connected to form rack systems. These racks provide medium-scale energy storage solutions and are designed to be modular, scalable, and efficient. Each rack comprises multiple packs connected in series or parallel. These battery racks are housed in cabinets with integrated thermal management and safety mechanisms.

Containerized energy storage systems are used at the industrial scale. These systems involve multiple racks assembled into a standardized container, providing large-scale, centralized energy storage.

In Pakistan, various manufacturers have introduced BESS. These systems are tailored to meet the specific energy needs of each sector, with capacities ranging from module-level solutions for smaller settings to containerized solutions for large-scale industrial operations. These variations in system design enable BESS to be flexible and scalable.

A detailed overview of the battery energy storage systems available in the Pakistan market sector-wise is provided below. Technical parameters are highlighted, including energy capacity, power ratings, efficiency, and operational features.

10.1.2 Residential Batteries in Pakistan

A market survey shows over 30 battery suppliers exist for the residential market. Since all these cannot be covered in the scope of this report, some of the main ones, along with their commonly used models, are listed in Table 18.

Table 18: Residential Batteries in Pakistan

Battery Name	Model	Technology	Capacity (Wh)	Usable (Wh)	C-Rate	%DOD	Country
Huawei	LUNA 20007-S1	LiFEPO4	6900	6900	0.5C	100%	China
Sungrow	SBH 100	LiFEPO4	10000	10000	0.2C	100%	China
Pylontech	UP5000		5120	4864		95%	China
Dyness	DL5.0	LiFEPO4	5120				China
BYD	LV Flex Lite	LiFEPO4	73	5000			China
BYD	LVS	LiFEPO4		4000			China
FoxEss	EP5	LiFEPO4	5180	4920			China
	EP11	LiFEPO4	10360				
Narada	51.2NESR100	LiFEPO4	5120		Max 1C	80%	China

Source: Author analysis based on market data.

Module-level batteries are primarily designed for the residential sector, offering flexible and scalable energy storage solutions. Paired with a hybrid inverter, a single module can provide 4kWh to 7kWh of energy per discharge, making them ideal for backup power and optimizing renewable energy usage. These modular systems allow multiple modules to be connected in series to match the power and voltage ratings of the hybrid inverter. This flexibility enables homeowners to expand their system over time, aligning with their energy independence goals and reducing reliance on the grid. As energy prices rise, such systems empower consumers to adopt sustainable energy practices while moving toward grid defection.

10.1.3 Commercial Batteries in Pakistan

For commercial-scale batteries, various players have tailored solutions for consumers. Others stack their battery modules based on consumer requirements to fulfill energy requirements. The technical power and energy rating for commercial-scale batteries range from 50kWh to 500kWh. Some commercial use cases require battery sizes as low as 20kWh. However, this report considers battery-based commercial-scale applications starting from 50kWh.

Two types of solutions are generally available for the commercial-scale applications mentioned in Section 3.2.1:

i. The first solution is a **modular inverter and battery system**. Battery modules, each with a specific capacity (5kWh to 10kWh), are stacked and connected to inverters, allowing users to incrementally increase the system size as their energy needs grow. This approach enables customization for specific energy and power requirements, making it ideal for businesses anticipating variable or growing energy demands. These systems are popular in small to medium-sized commercial setups like retail stores, offices, or healthcare facilities where energy needs vary based on operational hours. A modular system may start with 50kWh (or less) and expand to 200kWh by adding battery modules and scaling the inverter setup.

ii. The second solution is a **dedicated hybrid BESS system**. This solution involves dedicated, pre-engineered hybrid systems integrating the battery and inverter into a single package. These systems are optimized for seamless integration. Minimal setup and installation effort are required for such systems, as they are designed for quick deployment. These systems are suited for larger commercial establishments like data centers, banks, and supermarkets that require high reliability and predictable energy output. Dedicated hybrid systems come in predefined capacities, such as 100kWh or 200kWh, providing plug-and-play capability without requiring extensive system design or customization. These are typically containerized solutions.

While the batteries mentioned in Table 18 can be used for small-scale commercial applications in modular mode, Table 19 tabulates a dedicated BESS solution for full-scale commercial applications in the Pakistan market.

Table 19: Commercial Batteries in Pakistan

Battery Name	Technology / Cell Type	Model-PCS	Model BESS	Capacity kWh	C Rate	Display
HUAWEI	LFP	PCS2000-108k-MB1	LUNA2000-215-2S10	215	0.5	
SUNGROW	LFP	Hybrid Inverter	SBH 100 SBH200 SBH 300 SBH 400	10 20 30 40	0.7	
SUNGROW	LFP / 3.2V 280Ah	225kW	ST225kWh-110kW-2h	225	0.5	
ATESS	LFP	50kW to 300kW	HPS50, HPS100, HPS150	114-802.2		

Source: Author analysis based on market data.

10.1.4 Industrial Batteries in Pakistan

Industrial application batteries have higher energy storage ratings. They generally start from MWh level ratings and extend to higher capacities. These batteries are designed to handle high energy storage demands, scaling up to meet the needs of large-scale energy consumers. They typically begin at 1MWh and can scale to 10MWh or more, depending on requirements.

Industrial BESS are containerized, comprising multiple racks of battery modules, allowing scalability to match industrial energy needs. For example, a 5MWh system may have 10 racks of 500kWh each. An industrial consumer can deploy two 5MWh BESS containers to meet a 10MWh energy demand requirement.

Typical industrial-scale batteries available in Pakistan are provided in Table 20.

Table 20: Industrial Batteries in Pakistan

Battery Name	Technology / Cell Type	Model-PCS	Model BESS	Capacity kWh	C Rate	Display
HUAWEI	LFP	LUNA2000 -200KTL-H1	LUNA2000-1.0MWH-1H1 LUNA2000-2.0MWH-2H1 / 1H1	1016 2032	1C 0.5-1C	
SUNGROW	LFP	SC4000UD-MV SC5000UD-MV	ST2752UX	2752	0.7	

Source: Author analysis based on market data.

10.2 Load Profiles for a 10kW Sanctioned Load Consumer

Table 21: Load profiles for a 10kW Sanctioned Load Consumer - December, January, February

	Appliances	Power Rating (W/app)	Qty (app)	Usage Hours Off Peak (Hours) 9 PM to 5 PM	Consumption during Off peak hours (Wh)	Usage Hours during Peak (Hours) 5 PM to 9 PM	Consumption during Peak Hours (Wh)	Total Daily Consumption
1	Lights (LED)	15	10	3	450	4	600	1050
2	Fans	100	3	0	0	0	0	0
3	Refrigerators	500	1	20	10000	4	2000	12000
4	AC / Heater	1000	2	6	12000	2	4000	16000
5	Water Motor	500	1	2	1000	0	0	1000
6	TV	200	2	3	1200	3	1200	2400
7	Others Mobile laptop	200	7	2	2800	2	2800	5600
	Total in kWh				**27**		**11**	**38.05**

Source: Author analysis and estimations.

Table 22: Load profiles for a 10kW Sanctioned Load Consumer - March, April, May

	Appliances	Power Rating (W/app)	Qty (app)	Usage Hours Off Peak (Hours) 10 PM to 6 PM	Consumption during Off peak hours	Usage Hours Peak (Hours) 6 PM to 10 PM	Consumption during Peak Hours	Total Daily Consumption
1	Lights (LED)	15	10	7	1050	4	600	1650
2	Fans	100	3	12	3600	4	1200	4800
3	Refrigerators	500	1	20	10000	4	2000	12000
4	AC / Heater	1000	2	6	12000	2	4000	16000
5	Water Motor	500	1	2	1000	0	0	1000
6	TV	200	2	6	2400	4	1600	4000
7	Others Mobile laptop	200	7	2	2800	2	2800	5600
	Total in kWh				**33**		**12**	**45**

Source: Author analysis and estimations.

Table 23: Load profiles for a 10 kW Sanctioned Load Consumer - June, July, August

	Appliances	Power Rating (W/app)	Qty (app)	Usage Hours Off Peak (Hours) 11 PM to 7 PM	Consumption during Off peak hours	Usage Hours Peak (Hours) 7 PM to 11 PM	Consumption during Peak Hours	Total Daily Consumption
1	Lights (LED)	15	10	9	1350	4	600	1950
2	Fans	100	3	18	5400	4	1200	6600
3	Refrigerators	500	1	20	10000	4	2000	12000
4	AC / Heater	1000	2	13	26000	4	8000	34000
5	Water Motor	500	1	3	1500	1	500	2000
6	TV	200	2	6	2400	3	1200	3600
7	Others Mobile laptop	200	7	2	2800	2	2800	5600
	Total in kWh				**49**		**16**	**66**

Source: Author analysis and estimations.

Table 24: Load profiles for a 10 kW Sanctioned Load Consumer - September, October, November

	Appliances	Power Rating (W/app)	Qty (app)	Usage Hours Off Peak (Hours) 10 PM to 6 PM	Consumption during Off peak hours	Usage Hours Peak (Hours) 6 PM to 10 PM	Consumption during Peak Hours	Total Daily Consumption
1	Lights (LED)	15	10	7	1050	4	600	1650
2	Fans	100	3	18	5400	4	1200	6600
3	Refrigerators	500	1	20	10000	4	2000	12000
4	AC / Heater	1000	2	14	28000	3	6000	34000
5	Water Motor	500	1	2	1000	0	0	1000
6	TV	200	2	7	2800	3	1200	4000
7	Others Mobile laptop	200	7	2	2800	2	2800	5600
	Total in kWh				**51**		**14**	**65**

Source: Author analysis and estimations.

About IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

About the Authors

Haneea Isaad

Haneea is an Energy Finance Specialist at IEEFA. Based in Pakistan, she covers Asian energy markets with a focus on Pakistan's energy transition. hisaad@ieefa.org

Syed Faizan Ali Shah

Faizan is a renewable energy and power systems expert with over 15 years of experience in Pakistan's power generation, transmission, and distribution sector. faizan_alishah@hotmail.com