Assessing the Economic Viability of Solar Panels and Lithium-Ion Battery Storage Solutions in Addressing Pakistan's Energy Crisis

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Abstract

Pakistan's severe energy crisis, marked by chronic load shedding and reliance on costly fossil fuel imports, necessitates an urgent transition to sustainable alternatives. This study evaluates the economic feasibility of grid-tied solar photovoltaic systems integrated with lithium-ion battery storage for residential and commercial users in Pakistan. Employing a mixed-methods approach, the research combines primary data from structured surveys and interviews with 45 stakeholders (25 households, 15 small businesses, and 5 renewable energy industry experts) across Lahore, Islamabad, and Rawalpindi, alongside secondary market data and financial modeling. Unlike previous studies that focus either on solar alone or lack localized financial metrics, this study's primary contribution is the calculation of current, context-specific financial indicators—Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period—for solar-plus-battery systems in Pakistan. Key findings reveal a positive NPV of PKR 2,130,800, an IRR of 25.8%, and a payback period of 3.75 years, with average household savings of PKR 300,000 over five years. These results demonstrate that hybrid solar systems are both financially viable and environmentally beneficial. This paper provides actionable evidence for policymakers, investors, and households considering renewable energy adoption in Pakistan's evolving energy landscape.

Keywords: Solar Energy, Lithium-Ion Batteries, Renewable Energy, Energy Storage, Economic Feasibility, Sustainable Development.

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1. Introduction

Pakistan is fighting to overcome its terrible energy crisis, in which it is struggling to generate adequate electricity to supply its total population. The poor generation of electricity in the country is incapable of keeping up with the increasing power demand caused by the rapid development of population centers, as well as the industrial sector. Renewable energy technologies, such as solar energy, are promising solutions to the energy shortage problem in Pakistan because they are feasible (Bhutto, Bazmi, and Zahedi 2012). The success of integrating solar energy systems with lithium-ion battery storage will help power networks meet rising electricity demand and minimize pollution from conventional energy generation.

Due to the excessive dependence on nonrenewable energy sources such as coal, gas, and oil, Pakistan is experiencing severe environmental challenges and health risks. Traditional burning of fuel emits dangerous airborne chemicals that worsen climate change and contribute to the rise in global temperatures. The international fossil fuel prices are subject to market changes, which cause severe implications for the financial stability of Pakistan. The incorporation of renewable energy sources will increase the energy reliability of the nation and reduce the overall environmental effects in Pakistan, aligning the country with global sustainability efforts (Adnan et al. 2024).

While existing literature has established the technical potential of solar energy in Pakistan and separately examined battery storage technologies, a clear research gap remains. Previous studies have largely focused on either large-scale solar farms (such as the Quaid-e-Azam Solar Park) or theoretical financial models without incorporating primary stakeholder data. Furthermore, no recent study has systematically calculated context-specific financial metrics—NPV, IRR, and Payback Period—for integrated solar-plus-lithium-ion-battery systems specifically for Pakistani households and small businesses using current 2024 market prices. This study fills that gap by combining primary interview data from actual users and industry experts with rigorous financial modeling, thereby offering evidence-based insights that prior work has not provided.

The analysis of this research explores economic outcomes together with implementation aspects that stem from integrating silicon-based solar panel technologies and lithium-ion battery storage solutions in Pakistan. Key research questions guiding this study include:

1. Which financial advantages primarily exist when installing solar panels?
2. What ensures that solar energy systems stay operational when weather conditions deteriorate?
3. When choosing efficient solar panels, what selection criteria should be used?
4. What makes lithium-ion batteries the preferred storage option for energy applications?

The research questions allow us to understand how solar power would affect Pakistan's energy sector while identifying the benefits compared to traditional energy systems.

The increasing adoption rate of solar power throughout Pakistan faces multiple barriers that obstruct its extensive deployment. Numerous homes and businesses shy away from solar technology because they perceive its setup prices as too high, while they also lack understanding of its long-term advantages. Despite the enormous potential of improved storage systems, there exists under deployment of these technologies. Accelerated deployment of solar energy solutions nationwide requires addressing these obstacles directly (Seetharaman et al. 2019).

Pakistan began its solar energy embrace with the Quaid-e-Azam Solar Park established in Bahawalpur in 2015, which started with a 100 MW capacity before its growth to 1,000 MW. (Khosa et al. 2020). The share of solar power in Pakistan's electricity generation reached 6.8% in 2024, according to available data, while the previous rate was only 0.7%. The fast-rising popularity of solar energy demonstrates society's growing preference for renewable power alternatives.

This study examines integrated solar systems and storage solutions while investigating their financial profitability and their potential to meet Pakistan’s power requirements. This report is structured as follows: This research starts with a review of solar power and storage technology research before moving to the methodology, followed by results analysis, and ending with a summary of implications for future Pakistani energy policy.

2. Literature Review

The worldwide effort toward sustainable power systems now focuses intensely on connecting solar power generation with storage technologies. Pakistan's rising electricity requirements have prompted increasing research into renewable power production, and solar power presents itself as a strong candidate because of its availability and power generation efficiency in smaller facilities (Ibrahim et al. 2023). The existing body of literature shows essential information about the cost-effectiveness as well as technical performance alongside environmental advantages when solar power combines with battery storage units.

2.1 Technological Advancements in Solar and Storage Systems

The potential of solar and storage systems has been greatly enhanced by developments in energy technologies. In the discussion of advancements in small-scale energy storage technologies, Nguyen et al. (2017) pointed out that lithium-ion batteries are among the most dependable choices for solar system integration. The effectiveness and uses of several small-scale energy storage devices are demonstrated through comparisons.

Table 1: Comparison of Small-Scale Energy Storage Technologies

Technology	Description	Advantages	Disadvantages
Lithium-Ion Batteries	Rechargeable batteries using lithium compounds	High energy density, long life	High cost, temperature sensitivity
Sensible Thermal Storage	Uses materials to store thermal energy	Low cost, simple technology	Limited energy storage capacity
Other Technologies	Various emerging technologies	Potential for innovation	Uncertain performance

While the comparison above highlights the technical advantages of lithium-ion batteries, a critical review of the literature reveals that most existing studies have evaluated battery performance under controlled laboratory conditions or in temperate climates. Very few studies have examined lithium-ion battery degradation under Pakistan's specific environmental stresses, including summer temperatures exceeding 40°C, high humidity in coastal regions, and frequent dust accumulation. This limitation suggests that actual battery lifespan in Pakistan may differ from manufacturer specifications, a factor this study addresses by incorporating a 2% annual degradation rate based on local installer feedback.

2.2 Types of Solar and Storage Integration Models

There are several ways to integrate solar energy with storage devices, from off-grid options that promote local energy independence to hybrid renewable energy systems (HRES). According to Zerbino, Stefanini, and Aloini (2021) Hybrid models that combine solar photovoltaics (PV) and cutting-edge storage technologies provide both special difficulties and substantial opportunities for efficiency improvements. Pareto frontier analysis is used in their study to find the best options that balance economic considerations with emissions reduction.

Table 2: Comparison of Solar and Storage Integration Models

Model Type	Investment ($)	Cost Factors	Emissions Reduction (%)
Solar PV + Battery	PKR 490,500 to PKR 530,700 (approx. $1,800 - $2,000)	Installation costs: PKR 100 to PKR 160 per Watt; Maintenance: 1.5% of capital cost	Significant reduction due to the shift from fossil fuels
Off-grid Solutions	Varies based on setup	Equipment costs, installation, and maintenance	High reductions in emissions
Grid-tied Systems	Varies based on capacity	Connection fees and integration costs	Moderate reductions

A critical weakness in the existing literature is that most comparative studies of integration models rely on assumed cost figures rather than actual market data from developing economies. The investment costs shown in the table above, while useful for general comparison, are based on global averages that often fail to capture Pakistan's specific market conditions, including import duties, transportation costs, and currency fluctuations. This study responds to that gap by using actual 2024 price quotations from Pakistani solar vendors rather than assumed or adjusted international figures.

2.3 Design Considerations for Solar and Storage Solutions

Several aspects must be taken into account when designing solar systems, such as the influence on the environment, economic viability, and technology selection. For optimal efficacy, Shahnia and Endri (2020) suggested an approach that takes into consideration geographical limitations, solar radiation levels, and anticipated returns on investment. Understanding the design implications requires knowledge of the worldwide potential for solar energy under various Energy Return on Investment (EROI) levels.

Table 3: Key Design Parameters for Solar-Plus-Battery Systems in Pakistan

Parameter	Value
Photovoltaic Panel Price	PKR 35 to PKR 45 per Watt
Lithium-Ion Battery Price	PKR 490,500 to PKR 530,700
Installation Cost	PKR 100 to PKR 160 per Watt
Electricity Tariffs	PKR 175 per kWh (single phase), PKR 350 (three phase)
Geographic Solar Irradiance	Average: 5 to 7 kWh/mÂ²/day
Solar Panel Efficiency	18% to 20% (overall efficiency: 15% to 17%)
Annual Maintenance Cost	Estimated at 1.5% of the capital cost
Degradation Rate	PV: 0.5% loss/year; Battery: 2% loss/year
Expected Operational Lifetime	Solar Panels: ~25 years; Batteries: ~10 years

2.4 Challenges and Limitations of Integrated Systems

An integrated future with solar and storage mechanisms holds promising opportunities yet faces essential obstacles, such as high capital investment needs and energy usage decline. According to Shahnia and Endri (2020) certain EROI thresholds set boundaries for the realistic deployment of solar energy at a global scale. The adoption of emerging storage technology solutions faces barriers because of market conditions, even though they exist at an underdeveloped stage (Nguyen et al. 2017)**.**

What the literature fails to address adequately is how these challenges interact with one another in low-income settings. For example, high capital costs and lack of consumer awareness are typically discussed as separate barriers, yet they are deeply interconnected: limited awareness of financing options makes the upfront cost appear even more prohibitive. This study contributes to filling this gap by examining, through stakeholder interviews, how Pakistani households perceive and prioritize these interconnected barriers.

2.5 Role of Solar and Storage in Energy Optimization

The combination of solar energy with storage capacity creates an essential solution to maximize decentralized power systems and off-grid solutions. The systems described by Nguyen et al. (2017) have two main advantages: they improve network stability and decrease costs by employing effective storage methods. According to Zerbino et al. (2021) optimization algorithms used during system design enable cost reduction while achieving reliable operations.

2.6 Applications of Solar-Storage Solutions in Decentralized Energy Systems

Nuclear energy institutions can achieve a combination of better performance by integrating solar-powered storage solutions into their decentralized energy systems. Zerbino et al. (2021) utilized their methodology to analyze a farm hostel in Italy, which resulted in reduced costs with expanded emission reduction potential through off-grid applications.

2.7 Economic and Environmental Impacts of Solar-Storage Integration

The combination of solar-storage systems proves financially sustainable and delivers extensive environmental advantages. Sustainable practices become more prevalent due to both regulatory and market drivers, as well as environmental goals, which support industry growth. Maintaining minimal environmental trade-offs in solar projects proves essential for achieving sustained operation over the long-term.

Despite the general consensus that solar-storage integration reduces carbon emissions, the literature lacks recent, context-specific economic data for Pakistan. Most existing economic analyses for the country rely on 2018-2020 price data, when solar panels and lithium-ion batteries were significantly more expensive. Since 2021, global solar panel prices have declined substantially, meaning that older studies may have significantly overestimated payback periods for Pakistani adopters. This study provides updated calculations using 2024 prices, offering a more accurate picture of economic viability than earlier research.

Table 4: Environmental Impacts of Solar-Storage Integration

Factor	Impact on Solar Integration
Carbon Footprint Reduction	Significant reduction compared to fossil fuels
Land Use Requirements	Need for adequate space for solar farms.
Resource Sustainability	Long-term viability of solar resources

2.8 Evaluating Energy Return on Investment (EROI) for Solar-Storage Solutions

Solar-storage system viability depends on Energy Return on Investment metrics to check how output compares to input throughout their entire construction, operation, and maintenance phases. Areas receiving higher solar irradiation demonstrate higher implementation potential according to EROI metric assessments across regions.

2.9 Future Directions and Trends in Solar-Storage Integration

Future integration, according to industry forecasts, will use phase change materials (PCMs) and evolving thermochemical storage technology as they gain market adoption. Solar applications benefit from design-phase optimization with multi-objective math methods, according to Zerbino et al. (2021) , which resolves technical trade-offs along with economic considerations and implementation challenges.

3. Methodology

The evaluation of solar energy system integration with lithium-ion battery storage solutions in Pakistan's context uses a detailed methodology presented in this section. The research design brings together qualitative and quantitative tools to explore the complete picture of solar energy adoption hurdles while assessing their advantages.

3.1 Research Design

This research incorporates a dual data collection method that combines primary and secondary information sources. This research design enables scientists to identify both the complete financial feasibility of solar and storage systems and to answer the major questions detailed in the introductory segment.

3.2 Data Collection

3.2.1 Primary Data Collection

Primary data were collected through a mixed-methods approach combining structured surveys and in-depth interviews with stakeholders in Pakistan's renewable energy sector. Data collection took place between January and March 2024.

3.2.2 Sample Size and Composition

A total of 45 stakeholders participated in this study, distributed as follows:

3.2.3 Respondent Selection Criteria

Table 5: Sample Size and Composition of Survey Respondents

Stakeholder Category	Number of Participants
Households (with active solar-plus-battery systems)	25
Small and medium enterprises (SMEs) using solar power	15
Industry experts (renewable energy professionals, policymakers, researchers)	5
Total	**45**

Participants were selected using purposive sampling based on specific criteria relevant to the research objectives.

Households were eligible if they:

- Owned and operated a solar panel system with lithium-ion battery storage for at least 12 months
- Resided in Lahore, Islamabad, or Rawalpindi

- Voluntarily agreed to participate

Businesses were eligible if they:

- Had installed a solar-plus-battery system of at least 5kW capacity
- Had been using the system for a minimum of 6 months
- Operated within the retail, manufacturing, or service sectors

Industry experts were eligible if they:

- Held a professional position in renewable energy for 5+ years, OR
- Had published research on solar energy or battery storage in Pakistan, OR
- Were involved in energy policy formulation or solar project implementation

3.2.4 Geographic Scope

All respondents were located in Lahore, Islamabad, and Rawalpindi, the three urban centers with the highest concentration of residential and commercial solar installations in Pakistan.

3.2.5 Survey Design

A structured survey questionnaire was developed consisting of 18 questions divided into four sections:

For industry experts, an additional 6 open-ended questions were included.

3.2.6 Data Collection Procedures

Table 6: Structure of Survey Questionnaire

Section	Number of Questions	Focus
A	4	Demographics and system characteristics
B	5	Economic outcomes (savings, payback, financing)
C	5	Technical performance (reliability, weather issues, maintenance)
D	4	Barriers and recommendations

Surveys were administered in person at participants' homes or businesses. Each session lasted 20-35 minutes. Expert interviews were conducted in person (n=3) or via video call (n=2), lasting approximately 45 minutes each. All participants provided verbal consent, and no financial incentives were offered.

3.2.7 Response Rate

Table 7: Survey Response Rate by Stakeholder Category

Category	Invited	Participated	Response Rate
Households	35	25	71%
Businesses	22	15	68%
Industry experts	8	5	63%
Total	**65**	**45**	**69%**

3.2.8 Secondary Data

Secondary data are sourced from various credible publications, including:

Government reports on energy production and consumption in Pakistan.

Data gathered from market research shows the price structure of solar panels alongside battery systems.

A review of academic research focuses on solar energy technology development alongside storage solution advancements.

This data-set helps establish the basic framework of solar energy usage across Pakistan to utilize as background information for the current economic evaluation.

4 Economic Analysis

The economic feasibility of integrating solar systems with lithium-ion batteries is assessed using three key financial metrics: The analysis assesses financial considerations through three metrics including Net Present Value (NPV), Payback Period, and Internal Rate of Return (IRR).

4.1 Cost Estimation

The cost analysis uses photovoltaic panel market pricing together with lithium-ion battery market prices for calculations. The following ranges are considered:

Photovoltaic Panels: PKR 35 to PKR 45 per Watt.

Lithium-Ion Battery Storage Systems: Observers pay PKR 490,500 to PKR 530,700 for standard units, which the Fronius lithium-ion battery rated at 48V/100Ah demonstrates.

Installation Costs: The complete arrangement for installation and labor, together with equipment setup costs, is between PKR 100 and PKR 160 per Watt.

Detailed System Cost Breakdown (5kW system)

Table 8: Detailed Cost Breakdown for a Typical 5kW Solar-Plus-Battery System (PKR)

Component	Cost (PKR)
Solar panels (5kW @ PKR 40/Watt)	200,000
Hybrid inverter (5kW)	150,000
Lithium-ion battery (5kWh)	510,000
Mounting structure	75,000
Electrical components	40,000
Installation labor	125,000
Net metering fees	25,000
Transportation	25,000
Contingency (5%)	70,000
Total Initial Investment	**1,220,000**

Note: Analysis uses PKR 1,500,000 to account for variations in component quality and vendor pricing.

The analysis evaluates electricity tariffs by looking at today's per-kilowatt-hour rates, where single-phase connections cost around PKR 175 while three-phase connections cost PKR 350.

Table 9: Annual Savings Calculation for a 5kW Solar-Plus-Battery System

Parameter	Value
Daily solar generation (5kW system)	25 kWh
Annual generation	9,125 kWh
Less: System losses (15%)	1,369 kWh
Net usable annual generation	7,756 kWh

Grid tariff (PKR 175/kWh)	PKR 175
Annual grid cost avoided	PKR 1,357,300
Less: Annual maintenance (1.5%)	PKR 18,300
Less: Battery replacement fund	PKR 51,000
Gross Annual Savings	**PKR 1,288,000**

4.2 Performance Metrics

Solar panel performance evaluations within Pakistan depend on solar irradiation levels, amounting to 5 to 7 kWh/m²/day throughout geographic locations. The efficiency of modern solar panels ranges from 18% to 20%, while operational losses due to degradation factors are estimated at approximately:

Photovoltaic Panels: 0.5% loss annually.

Lithium-Ion Batteries: 2% loss in capacity annually.

Transactions through the solar panel network and battery storage system are expected to operate for 25 and 10 years, respectively.

4.3 Financial Computation

4.3.1 Net Present Value (NPV)

NPV is calculated as follows:

Assumptions for Financial Analysis

Table 10: Key Assumptions Used in Financial Analysis

Assumption	Value	Justification
Project lifetime (solar panels)	25 years	Standard manufacturer warranty
Project lifetime (batteries)	10 years	Typical lithium-ion battery lifespan
Discount rate	10%	State Bank of Pakistan policy rate (2024)
Annual electricity tariff escalation	5%	Historical average (2019-2024)
Solar panel degradation	0.5% per year	Standard for modern panels
Battery degradation	2% per year	Typical for hot climates
Annual maintenance cost	1.5% of capital cost	Industry standard

4.3.2 Net Present Value (NPV)

NPV is calculated as follows:

$$NPV = \sum \frac{Ct}{(1+r)^t} - C0$$

Where:

Ct = Cash flow at time t

r = Discount rate

t = Time period (in years)

C0 = Initial investment cost

Over the course of the project, the NPV calculation will assist in determining if the anticipated cash inflows from energy savings outweigh the initial investment expenditures.

4.3.3 Internal Rate of Return (IRR)

IRR is computed as the discount rate that makes NPV equal to zero:

$$0 = \sum \frac{Ct}{(1 + IRR)^t} - C0$$

Insight into the effectiveness of capital deployment in renewable energy projects can be gained by comparing this indicator with alternative investment possibilities.

4.3.4 Payback Period

The Payback Period is calculated using the formula:

$$Payback\ Period\ = frac\{Initial\ Investment\}\{Annual\ Cash\ Inflows\}$$

This metric is used to indicate the number of years it will take to save the amount of money spent on increased electricity charges to recover the initial investment.

4.4 Sensitivity Analysis

Sensitivity analysis is used to show the financial effects on NPV, IRR, and Payback Period due to the variation of relevant variables such as electricity tariffs, installation costs, and discount rates. The study finds important factors that affect solar and storage systems' economic output in different situations.

4.5 Scenario Modeling

Two main situations are modeled:

1. Base Case Scenario: This model reflects real-world market conditions, such as the price rates of electricity and the budgets for system installation.

2. Alternative Scenario: The model analyses the possible industrial developments as well as the government support, and the falling cost of installation and the increasing cost of electricity.

The economic viability of combining solar energy systems with lithium-ion battery storage options in Pakistan can be methodically assessed using this methodology. By combining both quantitative financial analysis and qualitative insights provided by primary data, this study aims at providing comprehensive results that can be used to educate stakeholders and policymakers on the potential benefits of transitioning towards renewable energy sources.

Table 11: IRR Calculation – NPV at Different Discount Rates

Metric	Description
Net Present Value (NPV)	The difference between the present value of cash inflows and outflows over time.
Internal Rate of Return (IRR)	Discount rate at which NPV equals zero.
Payback Period	Time required to recover the initial investment.

5 Results

Within this section, the results of the studies concerning the implementation of solar energy systems with lithium-ion battery storage solutions in Pakistan are discussed. Analysis results are transmitted that incorporate data obtained through surveys and interviews, and other research, with financial calculations based on methodology principles.

5.1 Solar Energy Systems: Economic Advantages

Likewise, based on the analysis, solar energy will be a far more cost-effective option than conventional power sources. The cost estimation demonstrates that individuals with solar power systems reduce the amount of money they pay as energy bills as opposed to traditional electric companies. Between the current electricity prices, costs of installing the power systems on battery storage solutions in Pakistan, and an average of five years, households that adopt solar installations will save about PKR 300,000. The findings are based on the data gathered with the help of surveys, interviews, and secondary research, as well as financial calculations made according to the developed methodology.

The analysis shows that the solar energy systems would result in great savings as compared to the conventional sources of electricity. The cost analysis of solar systems and the traditional electric bills show that households and business owners can save on their energy costs by adopting solar energy.

5.2 Financial Metrics

5.2.1 Net Present Value (NPV)

Due to higher savings than installation expenses, the integrated solar power with lithium-ion battery system delivers positive results according to the National Present Value computation. Using an initial solar setup investment of PKR 1,500,000 and annual savings of PKR 400,000, we reach a net present value figure when a 10% discount rate is used from the data collected through surveys, interviews, and secondary research, along with financial computations based on the established methodology.

Net Present Value (NPV) Calculation

Formula: $NPV = \sum_{t=1}^{25} \frac{400,000}{(1+0.10)^t} - 1,500,000$

Sum of present value factors (25 years at 10%) = 9.0770

Present value of inflows = 400,000 × 9.0770 = PKR 3,630,800

NPV = PKR 3,630,800 - 1,500,000 = **PKR 2,130,800**

Interpretation: A positive NPV of PKR 2.13 million means the solar-plus-battery system generates PKR 2.13 million more in value (in today's money) than it costs to install. This makes the investment highly attractive.

5.2.2 Internal Rate of Return (IRR)

Table 12: Discounted Payback Period Calculation (at 10% Discount Rate)

Discount Rate	NPV Result
10%	PKR 2,130,800
20%	PKR 400,000
25%	PKR 100,000
26%	PKR -20,000

IRR = 25.8%

Interpretation: An IRR of 25.8% substantially exceeds bank fixed deposit rates (15-18%) and government savings schemes (12-14%), confirming strong financial viability.

5.2.3 Payback Time

Payback Period

Simple Payback:

$$\frac{1{,}500{,}000}{400{,}000} = 3.75 \text{ Years}$$

Discounted Payback (at 10%):

Table 13: Discounted Payback (at 10%)

Year	Discounted Cash Flow (PKR)	Cumulative (PKR)
1	363,640	363,640
2	330,560	694,200
3	300,520	994,720
4	273,200	1,267,920
5	248,360	1,516,280

Initial investment (PKR 1,500,000) is recovered between Year 4 and Year 5.

Discounted Payback = 4.93 years

Interpretation: The investor recovers the full investment in less than 5 years, leaving over 20 years of remaining system life for pure profit.

5.3.Performance Metrics

5.3.1 Solar Panel Efficiency

Modern solar panels functioning in this study demonstrate performance levels between 18% and 20%. Environmental factors leading to operational inefficiencies lower total performance levels down to between 15% and 17%. The levels of solar energy produced in Pakistan are heavily determined by the geographic differences in solar irradiance measurements, which typically fall within a 5 to 7 kWh/m²/day range. Precise data indicate that lithium-ion batteries maintain 98% capacity following one year of service with an annual degradation rate of 2%.

Solar Irradiance: The geographic difference of solar irradiance in Pakistan is quite notable, with an average of 5 to 7 kWh/m 2 /day.

5.3.2 Battery Life

Lithium-ion batteries retain capacity at a rate of around 98% after one year of use, and then decrease by around 2% each year after. Lithium-ion batteries are also chosen because of their dependable performance cycles when it comes to integrated solar panel-based energy storage systems.

6. Limitations and difficulties

Nevertheless, despite the encouraging findings in terms of economic viability and performance indicators, there are several obstacles:

Expensive Initial Installation: The equipment installation cost required at the beginning of the installation of solar panel systems deters most of the would-be buyers.

Popularization: The shift to widespread solar use is still inhibited by the ignorance of the population about financial benefits as well as funding options.

Environmental Factors: Solar panels are subject to performance inconsistencies due to weather changes, but lithium-ion batteries tend to create a constant level of backup power during cloudy weather patterns.

7. Summary of Calculations

Table 14: Summary of Financial and Performance Metrics

Metric	Value
Initial Investment	PKR 1,500,000
Annual Cash Inflow	PKR 400,000
Discount Rate	10%
NPV	PKR 2,130,800
IRR	25.8%
Payback Period	3.75 years
Solar Panel Efficiency	15% - 17%
Battery Capacity Retention	~98% after one year

Through analysis, the economic potential of home and business solar power systems with lithium-ion battery storage in Pakistan is demonstrated. These affirmative results indicate that balancing short-term energy requirements and long-term sustainable goals through this energy management approach will be lucrative. Combined efforts of strategic communication efforts to educate the masses and low-cost infrastructure should help enhance the uptake of these technologies across the urban districts of Pakistan.

8. Discussion

Pakistan can resolve national energy challenges by bringing lithium-ion batteries in their solar systems. In the case of load shedding, increased expenditure on imported fuel and a ruined environment, solar energy with modern battery storage technology is a decent solution. Research demonstrates that increasing the share of renewables in the national energy mix is beneficial both in terms of energy security and the financial standing of the country. The move also helps Pakistan reach sustainable development goals, mainly focused on clean energy, economic progress, and problems related to the climate.

Economic Feasibility

Lots of research has shown that solar energy systems provide significant financial benefits for a long time in Pakistan. As the cost of needing more energy increases, solar technology gives both businesses and homeowners a solution that helps them save and makes sense. Having solar panels at home or in businesses cuts energy costs, which makes them an appealing choice or an extra source of power. Homeowners can expect to save an estimated PKR 300,000 if they add solar energy to their electricity from the grid over five years. Savings happen because less energy is needed from the national grid, inflation doesn't impact them as often, and new developments by makers and a rise in competition have made solar panels and related items less expensive.

Research done by Khan et al. (2022) proves that renewable energy investments are significant for both the environment and the economy. From these studies, we see that consumers and businesses can benefit from lower operational costs, greater energy independence, and steady access to energy. Solar power boosts financial peace of mind and simplifies the way a company operates because it reduces risks from costly fuel and energy supplies.

In addition, solar energy becomes more attractive because of its strong financial statistics. Iqbal et al. (2022) find through their analysis in 2019 that solar energy systems had an NPV of PKR 250,000 at the beginning. This figure suggests that once you adjust the future savings from energy to today's figures, the panel cost is much lower. All things considered, after the initial outlay, the technology quickly pays off its cost while still helping the organization save money for years.

Furthermore, the Internal Rate of Return (IRR) justifies the financial attractiveness of solar energy. Sherrard-Smith et al. (2020) document that solar investments outperform many traditional ways of investing, like fixed deposits, buying land, or stocks in unstable markets. So, the amount of money solar systems bring in as time goes by is suitable and can be relied on. Solar energy gains even more attention because it pays off in a short time before paying off. Shahbaz et al. (2021) mention that having a payback time of just 3.75 years, solar installations are attracting both households and businesses who want to recoup their expenses fast. Following this phase, almost free electricity is available to users for the system's average useful life of 20 to 25 years.

These new findings point to solar energy being good for our planet and our wallets. Because solar energy is financially available, more people know about it, and the government backs it, it can take hold as the go-to energy solution in Pakistan. The ability to pay for such projects can help ease today's energy crisis and also raise the economy through new work in manufacturing, installing, and looking after solar equipment.

Performance Metrics

Solar power systems work well based on the grade of the panels and the circumstances surrounding their use. In 6 areas across the country, solar energy production is made possible because of the 5 to 7 $kWh/m^2/day$ of solar radiation the area experiences. Still, things like dust, the sun's heat, and obstructions can lower the efficiency of solar panels, which usually work at around 18% to 20%. They point out that greater panel quality and accurate setups help lower these efficiency decreases.

To get the best results out of solar, site-specific checks must be done. Their use helps place solar panels where they will be most effective and pick the best system size according to the amount of sunlight your area gets. What's more, lithium-ion batteries in these systems have proved to be reliable, with a stable efficiency of 98% in their first year. From there, performance drops each year at an average pace of 2%.

Even so, battery storage greatly increases the system's dependability. Excess solar energy collected during the day is held by the batteries, and as soon as sunlight or energy decreases, the batteries start releasing it. Based on research from Butt et al. (2021), this capability supports a stable energy supply and lessens reliance on the national electrical network. Tariq, Sadaf, and Muhammad (2022) explain that by using battery storage, renewable supply can be managed, and electricity is provided during dark or cloudy periods.

Challenges and Limitations

While solar energy has many useful benefits, it is not used more widely in Pakistan because of a number of difficulties. For many, solar panels and battery systems are too expensive to buy and install, which acts as a main obstacle. While they can save lots in the long run, many people find the first outlay too costly. According to Haque et al. (2023), financial problems severely hinder the process.

Raising public understanding is very important. People often aren't informed about the lasting advantages and options like subsidies and paying in instalments**.** Iftikhar et al. (2021) discovered that awareness of the money and environmental benefits of solar energy drives many people's interest in installing it.

The environment creates extra problems. Panels can become a lot less efficient if they get dirty with dust. The equipment must be routinely cleaned and maintained for optimal performance. Mahmood and Zubairi (2019) points out that neglecting solar systems may lead to poor performance, even for high-quality systems.

Lithium-ion batteries are efficient, but still cause problems with finding resources, making them, and what to do with them at the end of their life. Khan and Ahmad suggest that poor battery waste management may cause harm to the environment, so we should have better ways to recycle batteries.

Policy Implications

The Pakistan government must take decisive action to encourage many building Solar plus Battery projects. Making sure there are strong financial support tools helps reduce the start-up costs for those wishing to participate. A government could support solar and battery use by offering reduced solar panel costs, benefits for eco-energy investments, and no-to-low-interest loans for all users, especially low- and middle-income households. Thanks to federal action, solar energy would become more accessible to both small companies and communities, as well as to educational institutions in rural areas.

But to make a real difference, we also need to ensure that information about treatment is accessible to everyone. Campaigns help people learn how solar energy can decrease their electric costs, offer insurance against increasing energy prices, and raise the value of their homes. In addition, these campaigns ought to list the environmental benefits, such as less carbon, cleaner air, and more energy independence. According to Zafar et al. (2018), accurate information is crucial since it motivates people to choose sustainable practices and eco-friendly technologies.

The government should take additional steps to create practical regulations and infrastructure. Making permits and installation for solar systems easier can eliminate the delays or discouragement that many people face when installing them. If approval processes are improved, single windows are used, and policies are easy to follow, the deployment rate can be faster. Also, making local solar panels and batteries can bring down the need for imports, provide employment, and eventually cut costs for technology. Giving training, tax benefits, and infrastructure help to local industries will gain support for the domestic renewable energy field while also increasing the country's self-reliance.

Moreover, teamwork between the government, the private sector, and international groups can support the creation of new models such as pay-as-you-go solar, energy-as-a-service, and public-private partnerships for energy. As a result, these models bring solar power to remote locations where the grid cannot be easily used.

Simply, by ensuring excellent incentives, informing the public, lessening the regulations, and building local skills, Pakistan's government can create a large user base for solar energy along with battery storage. Following several approaches at once secures our energy supplies, protects nature, and improves our progress toward a sustainable future.

Future Directions

A lot of growth and innovation is possible in solar energy systems moving forward. Using PCMs and thermochemical storage devices can help us improve energy storage. They can, in some cases, even make lithium-ion batteries more effective.

On designing, Butt et al. (2021) stresses that integrated approaches must include concerns about the economy, the environment, and technology. They help make solar technology perform better while also keeping costs down.

Renewable energy will help Pakistan's economy thrive as it grows. Introducing modern solar and storage devices will lessen the nation's need for fossil fuels, avoid energy shortages, and strengthen the path towards a sustainable energy system.

Conclusion

This research shows that solar energy, combined with lithium-ion batteries, can be profitable and clean in Pakistan. Such findings point to renewable energy options as technically possible, and also capable of saving homes and companies significant sums in the long run. This appears to be a useful means of addressing the energy issues in the country, with the good outcomes and the certain prices of solar and batteries. Smart grids justify their value by providing dependable energy at peak demand times and reducing fossil fuel use.

However, the reason why many consumers do not use such technologies is that these are expensive and not many people have heard about them. Many individuals are not aware of the benefits of utilizing financial products, saving, and receiving government assistance. To realize this potential, the people need to be educated about solar energy and provided with simple and inexpensive methods of paying for battery storage. Such investments need to be made to aid in keeping these systems sustainable, beginning with better recycling of lithium-ion batteries.

Going forward, Pakistan stands at a crucial point in its route to renewable energy. The renewable energy sector is improving, and there are new storage devices like thermochemical storage and phase change materials that can be researched and utilized. Also, by supporting local factories, making solar installation easy, and including green investments, solar integration becomes possible.

Pakistan can transform its energy landscape immensely if it adopts public participation, financial resourcefulness, and forward-looking policies. The use of renewable energy will resolve the energy mess that exists currently, support economic development, minimize the burden on nature, and turn the country into the pioneer of sustainable development in South Asia. Pakistan can be a role model to other developing nations that wish to lessen their impact on the environment since it is currently taking action.

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