

FUTURE PRIORITIES FOR SOLAR ENERGY INSTALLATIONS IN UZBEKISTAN: GRID INTEGRATION, DISTRIBUTED APPLICATIONS, AND INTELLIGENT OPERATION

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Abstract

The future development of solar energy in Uzbekistan requires an in-tegrated approach to generation, electricity networks, storage, and end-use applications. This thesis examines the priorities that should guide future installations, drawing on international research and documented national projects. The analysis considers utility-scale photovoltaic sys-tems, rooftop installations, agricultural applications, battery storage, and intelligent maintenance. It argues that installed capacity alone is insuffi-cient to evaluate development: delivered energy, reliability, lifecycle cost, and resource efficiency must also be assessed. Recent solar-plus-storage in-vestments demonstrate a transition toward more integrated infrastructure, while distribution modernization and irrigation reform highlight comple-mentary needs. A research framework is proposed to compare installation strategies under local operating conditions. The principal conclusion is that Uzbekistan should coordinate solar expansion with network readi-ness, demand characteristics, and long-term operational capability.

Introduction

Solar energy can contribute to Uzbekistan's electricity supply through large power plants, distributed rooftop systems, and installations serving specific industrial or agricultural loads. However, the value of these applications depends on when electricity is produced, where it is consumed, and whether the network can accommodate it. Future planning should therefore consider the complete electricity system rather than treating solar installations as isolated generation assets.

The International Energy Agency's solar roadmap for Uzbekistan emphasizes clear policy objectives, appropriate incentives, self-consumption, and power-system flexibility [1]. Although published in 2022, it provides a useful analytical foundation. Its recommendations should be interpreted alongside subsequent investments and changing operating conditions, rather than presented as a description of current legislation.

A central distinction concerns installed capacity and useful energy. Photo-voltaic capacity describes rated power, whereas annual generation depends on weather, equipment performance, availability, and operating restrictions. Electricity reaching consumers may differ further because of storage losses, network losses, and curtailment. Accordingly, a future installation should be assessed through delivered electricity and service quality in addition to its nameplate capacity.

This thesis addresses the following question: which installation and operational priorities can make Uzbekistan's future solar development more reliable, economically useful, and environmentally responsible? The analysis is a source-based discussion and proposed research agenda. It does not report new field measurements or assume a predetermined national energy-saving percentage.

Evidence from Related Research and National Developments

Research on integrated energy planning supports coordinated investment in generation, transmission, and storage. Moradi-Sepahvand and Amraee [2] proposed a multi-period expansion model incorporating renewable uncertainty, network congestion, storage location, and operational flexibility. Their evaluation used the IEEE reliability test system. Consequently, the study provides a planning

methodology rather than direct evidence about the optimal configuration for Uzbekistan.

Recent national projects illustrate the relevance of this integration. In January 2026, the Asian Development Bank announced financing for a 300 MW photovoltaic plant and a 75 MWh battery energy storage system in Guzar, Kashkadarya. The project also includes transmission and substation facilities [3]. Separately, an October 2025 financing announcement covered the Samarkand 1 and 2 solar-plus-storage projects [4]. These announcements indicate an investment direction; financing approval should not be equated with verified operational performance.

Network conditions remain a material constraint. A May 2025 World Bank release reported technical distribution losses of approximately 13% in 2024 and described a modernization program intended to improve renewable integration and supply reliability [5]. This estimate concerns distribution infrastructure, not losses within photovoltaic modules. Nevertheless, it demonstrates why generation investment and network improvement should be coordinated.

Operational research provides another complementary perspective. Bommès et al. [6] demonstrated automated extraction and classification of photovoltaic modules from aerial infrared videos, with reported test accuracy exceeding 90% for ten anomaly categories. Such methods can accelerate inspection, but their contribution to energy production depends on successful diagnosis and corrective maintenance. Detection accuracy alone does not establish recovered electricity. Together, these sources support three conclusions: installation planning should account for system constraints; storage should be evaluated against specific services; and monitoring should be connected to verified operational outcomes.

Future Priorities for Solar Installations

Coordinate Utility-Scale Development with Grid Readiness

Large photovoltaic plants should be selected through combined resource, land, and network assessment. High solar irradiation does not automatically identify the

most valuable location. Connection distance, substation capacity, congestion, environmental sensitivity, and proximity to demand can alter project value. A proposed planning priority is to compare candidate sites using hourly generation and demand profiles. Network studies should examine voltage conditions, congestion, and the ability to accommodate generation during periods of high solar output. Project evaluation should include expected curtailment and connection costs rather than relying exclusively on annual energy estimates. The research implication is that the preferred installation may differ from the site with the highest theoretical yield. A somewhat lower-resource location could provide greater delivered energy or lower total system cost if it has a stronger connection and better demand alignment. This is an analytical possibility to test, not a finding established for a particular Uzbek region.

Design Storage around Defined Operational Services

Battery storage should be sized for a documented purpose, such as shifting daytime generation, supporting critical loads, or managing short-term variability. Solar capacity and battery capacity should not be linked through an arbitrary universal ratio.

Storage specifications must distinguish power, measured in MW, from stored energy, measured in MWh. For example, a reported 75 MWh energy capacity does not establish the battery's discharge power or guaranteed duration. Assessment also requires information about usable capacity, efficiency, degradation, reserve requirements, and operating limits.

For Uzbekistan, the proposed research focus is to compare solar-only, solar-plus-storage, and demand-flexibility configurations under the same assumptions. Batteries introduce additional cost and losses, so their benefit should be demonstrated through improved service or reduced system expenditure. Scheduling flexible loads during solar hours should be evaluated alongside storage rather than excluded from the comparison.

Expand Rooftop Solar through Demand-Matched Design

Distributed installations offer opportunities on universities, public buildings, commercial premises, and suitable residential rooftops. Their proposed advantage is generation close to consumption, although actual benefits depend on building demand and distribution-network conditions.

A useful initial application is a monitored university installation. It could combine electricity generation with student training in energy measurement, forecasting, and control. Before installation, the study should assess roof condition, shading, structural suitability, electrical infrastructure, and hourly consumption.

Self-consumption should be a central design variable. Oversizing a system without understanding export arrangements can reduce its economic value. Conversely, demand management may improve the use of locally generated electricity. Future studies should compare alternative system sizes and operating schedules using verified consumption records and the applicable commercial arrangements.

Backup supply requires separate consideration. A conventional grid-connected photovoltaic system should not be assumed to provide electricity during an outage. Critical-load service requires an explicitly designed backup configuration, appropriate control, and sufficient energy availability.

Integrate Solar Applications with Agricultural Efficiency

Agriculture is an important application area because electricity and water management are closely connected. The World Bank's May 2025 irrigation announcement reported approximately 7.2 billion kWh of annual electricity consumption by irrigation pumping stations [7]. This figure demonstrates the scale of pumping demand, but does not establish how much could economically be supplied by solar installations.

Solar-assisted pumping should be evaluated alongside pump efficiency, irrigation scheduling, and water availability. Lower-cost energy can encourage additional pumping, so electricity savings should not be treated as proof of improved water sustainability. Flow measurement and defined irrigation requirements are necessary.

Where technically suitable, water storage could help separate pumping time from irrigation delivery time. Its feasibility depends on elevation, storage losses, land availability, and operating requirements. Agrivoltaic installations also warrant pilot studies, but should be judged through both electricity output and agricultural outcomes. Crop response, machinery access, irrigation compatibility, and land productivity must be measured locally before wider adoption.

Make Intelligent Monitoring Part of Installation De-sign

Monitoring should be specified during procurement and commissioning. Persistent equipment identifiers, accessible operating records, and environmental measurements would make later fault diagnosis and performance comparison more effective.

Computer vision offers a research opportunity through drone-based thermal inspection and RGB assessment of shading or visible contamination. These observations should be combined with electrical data to distinguish candidate anomalies from confirmed faults. Maintenance recommendations should consider expected energy recovery and intervention cost.

For local validation, models should be tested across independent installations, inspection dates, and sensors. Repeated images of the same module should not be distributed across training and test sets. Operational assessment should report false alarms, confirmed defects, inspection time, and electricity recovered after maintenance.

Proposed Research Framework

A future study could compare three representative applications: a utility-scale plant, a university rooftop, and an agricultural pumping installation. The final sample should depend on access, available measurements, and an appropriate study design.

Each application should be evaluated using hourly generation, consumption, weather, outages, and maintenance records. The analysis would compare alternative installation sizes, storage configurations, and demand-management

strategies. Financial evaluation should include capital expenditure, connection costs, maintenance, replacements, and uncertainty in future operating conditions. Edelivered is electricity supplied to the defined load or connection point, and PPV_{rated} is photovoltaic rated capacity. The measurement boundary must remain consistent across comparisons. Where batteries charge from both solar and the grid, source attribution is required.

Additional indicators should include curtailment, self-consumption, critical-load availability, lifecycle cost, and, for pumping applications, water delivered per unit of electricity. Sensitivity analysis should examine demand growth, storage degradation, weather variability, and maintenance expenditure.

Limitations and Conclusion

The proposed priorities require site-specific validation. Announced projects do not provide complete evidence of operating performance, and results from international research cannot be transferred directly to Uzbek installations. Financial outcomes depend on project contracts and local conditions, while agricultural applications require explicit consideration of water management.

The future of solar installations in Uzbekistan should combine capacity expansion with grid readiness, appropriately designed storage, demand-matched distributed systems, and reliable maintenance. Utility-scale projects can support electricity supply, while rooftop and agricultural installations can address particular consumption needs. Their relative value should be evaluated through delivered energy, service reliability, lifecycle expenditure, and resource efficiency. The main research opportunity is to establish which combinations work best under local conditions. Coordinated field measurements and transparent comparisons would provide a stronger basis for future investment than capacity targets alone. Intelligent monitoring can support this transition by connecting installation performance with timely, verifiable operational decisions.

References

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