

Operational Benefits of Photovoltaic Solar Energy Integration in Kenya National Youth Service TVET Training Institutions

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ABSTRACT: This paper examines the operational benefits associated with integrating photovoltaic (PV) solar energy in Kenya National Youth Service (NYS) Technical and Vocational Education and Training (TVET) institutions. Technical and vocational training institutions depend heavily on reliable electricity to support workshops, laboratories, ICT facilities, and administrative operations. However, rising electricity costs and frequent power interruptions continue to undermine the quality and continuity of training delivery. The study adopted a pragmatic research philosophy and employed a mixed-methods research design. The target population comprised five principals, five heads of departments, and fifty trainers from five NYS TVET institutions. Data were collected using structured questionnaires and interview schedules. The findings revealed that PV solar energy integration had generated substantial operational benefits (overall mean = 4.12). Respondents agreed that solar energy systems enabled institutions to operate effectively during power outages (mean = 4.40), enhanced the efficiency of workshops, laboratories, and ICT equipment (mean = 4.20), improved overall operational performance (mean = 4.16), and enhanced electricity reliability (mean = 4.04). The study concluded that photovoltaic solar energy is a technically feasible and operationally sustainable solution for improving institutional performance in NYS TVET institutions. It recommends expansion of solar infrastructure with battery storage, strengthened technical capacity, and integration of solar energy into institutional strategic plans.

KEYWORDS: PV solar energy, operational benefits, energy reliability, TVET institutions, Kenya National Youth Service, technical training

1. INTRODUCTION

The global transition toward renewable energy has increasingly positioned solar photovoltaic (PV) systems as a cornerstone of sustainable development, particularly in the education sector. Technical and Vocational Education and Training (TVET) institutions, which are responsible for equipping learners with practical and industry-relevant skills, depend heavily on reliable electricity to support workshops, laboratories, ICT facilities, and administrative operations. However, in many developing countries, including Kenya, educational institutions face persistent challenges of rising electricity costs, unreliable grid power, and frequent power outages that disrupt teaching, learning, and institutional administration.

Sub-Saharan Africa has witnessed a surge in solar energy adoption, driven by the need to improve energy access and reduce operational costs. In 2024, the continent installed 2.4 GW of new solar capacity, with projections indicating a 42% growth in 2025 (Global Solar Council, 2024a). Off-grid solar solutions have been instrumental in expanding electricity access in the region. Between 2020 and 2022, off-grid solar provided 55% of new connections in Sub-Saharan Africa (World Bank, 2024). Kenya has been at the forefront of renewable energy adoption in Africa, with solar-installed capacity reaching 542.4 MW by June 2025 (Energy and Petroleum Regulatory Authority [EPRA], 2025). Institutions across the country have begun embracing solar energy to mitigate rising electricity costs and improve energy reliability.

The Kenya National Youth Service (NYS) Technical and Vocational Education and Training institutions play a crucial role in equipping youth with practical skills in areas such as electrical installation, building technology, mechanical engineering, and automotive technology. These programmes rely heavily on workshop-based training and modern electrical equipment, making a stable and affordable energy supply essential for effective instruction. However, similar to many public training institutions in Kenya, NYS TVET institutions face operational challenges related to fluctuating grid electricity, high energy costs, and occasional power interruptions, which can disrupt practical training sessions and limit the effective utilization of training equipment.

Educational institutions depend on reliable electricity to support learning, administration, security, and digital technologies. However, rising electricity costs and grid instability can place significant pressure on operating budgets and daily operations. In educational environments, interruptions can affect classroom activities, administrative operations, internet connectivity, and essential support services. Reliable access to electricity is particularly important in TVET institutions, where practical training in workshops and laboratories requires uninterrupted power supply.

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Despite global and regional advancements in solar energy adoption, many public institutions in Kenya, including TVET institutions, continue to rely heavily on the national grid, resulting in high operational costs and frequent disruptions to training activities. While the economic benefits of solar energy adoption have been widely documented, limited empirical evidence exists regarding the specific operational benefits of photovoltaic solar energy integration in public TVET institutions, particularly within the NYS framework. This study therefore sought to determine the operational benefits associated with integrating PV solar energy in NYS TVET institutions.

The specific objective of this paper is:

1. To determine the operational benefits associated with integrating PV solar energy in NYS TVET institutions.

The study was guided by the Technology-Organization-Environment (TOE) Framework introduced by Tornatzky and Fleischer (1990) and the Resource-Based View (RBV) Theory proposed by Barney (1991). The TOE framework categorizes influencing factors into technological, organizational, and environmental contexts, providing a comprehensive approach to understanding the factors that influence the adoption of technological innovations within organizations. The RBV theory emphasizes that organizations can achieve sustained competitive advantage by acquiring, developing, and effectively managing valuable, rare, inimitable, and non-substitutable resources. In the context of solar energy systems, reliable renewable energy infrastructure can be seen as a strategic resource that offers operational advantages including improved energy reliability, reduced disruptions, and enhanced institutional efficiency.

2. RESEARCH METHOD

2.1 Research Design

This study adopted a mixed-methods research design, in which both quantitative and qualitative data were collected concurrently, analyzed separately, and then integrated during interpretation. This design was appropriate because it allowed the study to obtain both measurable evidence on operational benefits from photovoltaic solar energy and in-depth insights into institutional experiences and implementation dynamics within Kenya National Youth Service TVET institutions (Creswell & Creswell, 2023).

2.2 Study Area and Target Population

The study covered 5 NYS TVET institutions in Kenya. These institutions included: NYS Advanced Building School - Gilgil, NYS Engineering Institute - Nairobi, Nairobi Engineering Craft School - Nairobi, NYS Technical College Mombasa, and Vocational Training Institute - Nairobi. The study focused on these five institutions because they represent a diverse mix of technical training specializations and geographical locations, encompassing both central and coastal regions of Kenya.

The target population comprised 5 principals, 5 heads of departments, and 50 trainers from the five NYS TVET institutions. These respondents were considered appropriate because principals and heads of departments are responsible for institutional management, infrastructure planning, and resource allocation, including decisions related to energy management and the adoption of solar systems. Trainers are directly involved in the daily operation of workshops and training equipment that rely on electricity, making them well positioned to provide practical insights on the operational impact of solar energy adoption.

2.3 Sampling Procedure and Sample Size

The study employed purposive and stratified sampling approaches to select respondents from the five NYS TVET institutions. Purposive sampling was used to select the principals and heads of departments because they occupy key administrative and managerial positions that influence institutional decision-making on energy management and the adoption of solar energy systems (Campbell et al., 2020). For the trainers, a stratified random sampling technique was used to ensure proportional representation from different technical departments within each institution.

Given the relatively small and well-defined population, a census approach was employed to select all eligible respondents. This meant that all five principals, all five heads of departments, and all fifty trainers from the selected NYS TVET institutions were included in the study. Including the entire population minimized sampling error, enhanced the accuracy of findings, and ensured that the perspectives of all key stakeholders involved in the management and operational use of solar energy systems were captured (Babbie, 2021; Mugenda & Mugenda, 2020).

2.4 Data Collection Instruments

A structured questionnaire and unstructured interview guide were applied in this study. The questionnaire was organized into sections designed to collect specific types of data relevant to the study. Section A captured respondents' basic information including gender, age, level of education, and work experience. Section D focused on determining the operational benefits associated with integrating PV solar energy in NYS TVET institutions. All items were measured on a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). Interview schedules were useful in the collection of qualitative data from principals and heads of departments to complement quantitative findings (Dubey & Kothari, 2022; Mwita, 2022).

2.5 Validity and Reliability

Content validity was established through expert review by a panel of experts from the Electrical and Electronic Technology Department, who evaluated the relevance, clarity, and comprehensiveness of each item. Feedback from the experts was used to revise items to ensure that the instrument fully captured the constructs being measured (Creswell & Creswell, 2023). Reliability

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of the questionnaire was tested using Cronbach's Alpha model, which evaluated internal consistency. The Cronbach's Alpha value for the operational benefits section was 0.87, exceeding the generally accepted threshold of $\alpha \geq 0.7$, indicating that the questionnaire was sufficiently reliable for data collection.

2.6 Data Analysis

Quantitative data collected through questionnaires were analyzed using descriptive statistics with the aid of SPSS version 30.0. Descriptive statistics such as means, frequencies, and standard deviations were used to summarize the data. Qualitative data from interview guides were analyzed using thematic content analysis, where responses were compared and summarized in accordance with the study's objectives. The use of content analysis allowed for objective, systematic, and qualitative description of the communication's content (Dubey & Kothari, 2022; Omona, 2013).

2.7 Ethical Considerations

Ethical considerations that guided this study included seeking permission from the University of Eldoret Post Graduate Examination Board and obtaining permission from NACOSTI and NYS TVET institutions to conduct research. The purpose of the study was disclosed to participants from the onset, potential risks were explained, and privacy of participants was respected. Finally, respect for intellectual property was guaranteed by giving proper acknowledgement or credit for all contributions to this study, acknowledging all sources to avoid plagiarism.

3. RESULTS AND ANALYSIS

3.1 Response Rate and Demographic Characteristics

The study targeted 50 respondents drawn from Kenya National Youth Service (NYS) TVET training institutions. All the 50 questionnaires administered were successfully completed and returned, representing a response rate of 100%. According to Mugenda and Mugenda (2019), a response rate above 70% is considered excellent for statistical analysis. Therefore, the response rate achieved in this study was adequate for reliable data analysis and generalization of the findings.

3.1.1 Gender of Respondents

Table 1. Gender of the Respondents

Gender	Frequency	Percent
Male	32	64.0
Female	18	36.0
Total	50	100.0

The findings indicate that 32 (64.0%) of the respondents were male while 18 (36.0%) were female. This implies that the majority of employees in NYS TVET institutions involved in solar energy implementation and management are male. However, the participation of female respondents demonstrates that both genders are represented in institutional decision-making regarding renewable energy adoption.

3.1.2 Age Bracket of Respondents

Table 2. Age Bracket of Respondents

Age Bracket	Frequency	Percent
Below 25 Years	14	28.0
25-34 Years	20	40.0
35-44 Years	9	18.0
45-54 Years	4	8.0
Over 54 Years	3	6.0
Total	50	100.0

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The results show that 20 respondents (40.0%) were aged between 25-34 years, 14 respondents (28.0%) were below 25 years, 9 respondents (18.0%) were between 35-44 years, 4 respondents (8.0%) were aged 45-54 years, while only 3 respondents (6.0%) were above 54 years. These findings indicate that the majority of respondents were relatively young and active employees who are likely to possess current knowledge regarding renewable energy technologies and institutional operations.

3.1.3 Highest Level of Education

Table 3. Highest Level of Education of Respondents

Highest Level of Education	Frequency	Percent
Higher Diploma	6	12.0
Bachelor	29	58.0
Masters	12	24.0
Doctorate	3	6.0
Total	50	100.0

The findings indicate that 29 respondents (58.0%) possessed Bachelor's degrees, 12 respondents (24.0%) held Master's degrees, 6 respondents (12.0%) had Higher Diplomas, while 3 respondents (6.0%) possessed Doctorate qualifications. The results demonstrate that respondents were highly educated, implying that they were capable of providing informed opinions regarding the operational benefits of PV solar energy integration.

3.1.4 Years of Experience

Table 4. Years of Experience

Years of Experience	Frequency	Percent
Below 5 Years	3	6.0
5-7 Years	30	60.0
8-10 Years	10	20.0
Over 10 Years	7	14.0
Total	50	100.0

The findings indicate that 30 respondents (60.0%) had worked between 5-7 years, 10 respondents (20.0%) had worked for 8-10 years, 7 respondents (14.0%) had over 10 years of experience, while 3 respondents (6.0%) had worked for less than five years. These findings suggest that the majority of respondents had sufficient experience to understand institutional operations and the implementation of photovoltaic solar energy systems.

3.2 Operational Benefits of PV Solar Energy

The objective of this study was to determine the operational benefits associated with integrating PV solar energy in NYS TVET institutions.

Table 5. Descriptive Statistics on Operational Benefits Associated with Integrating PV Solar Energy

Statement	N	Mean	Std. Deviation
The integration of PV solar energy has improved the reliability of electricity supply in the institution.	50	4.04	1.177
PV solar energy systems have reduced interruptions in teaching, training, and administrative activities.	50	3.80	.969

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Statement	N	Mean	Std. Deviation
The use of PV solar energy has enhanced the efficiency of operating workshops, laboratories, and ICT equipment.	50	4.20	.833
PV solar energy systems have enabled the institution to operate effectively during power outages.	50	4.40	.782
The integration of PV solar energy has improved the overall operational performance of the institution.	50	4.16	1.113
Overall Mean Results	50	4.12	0.975

The results in Table 5 revealed that respondents generally agreed that integrating photovoltaic (PV) solar energy has improved the operational performance of Kenya National Youth Service TVET institutions. The respondents strongly agreed (mean = 4.40) that PV solar energy systems had enabled their institutions to operate effectively during power outages, indicating that solar energy has enhanced the reliability of institutional operations. This finding is consistent with observations from other educational institutions in Kenya, where solar-plus-storage systems have enabled facilities to generate approximately 95% of their electricity from solar energy, significantly reducing reliance on grid power and providing greater protection against utility outages.

Similarly, respondents agreed (mean = 4.20) that the use of PV solar energy had enhanced the efficiency of operating workshops, laboratories, and ICT equipment, demonstrating that reliable electricity has improved the functioning of practical learning facilities. This finding aligns with evidence from Khwisero Technical and Vocational College, where a 60kVA solar power system now powers all machines and key services, ensuring uninterrupted 24-hour electricity supply with no reported blackouts, thereby enhancing training activities, assessment processes, and overall administrative operations.

The respondents also agreed (mean = 4.16) that integrating PV solar energy had improved the overall operational performance of their institutions, while they further agreed (mean = 4.04) that solar energy had improved the reliability of electricity supply. At Machakos Town Technical and Vocational College, the solar PV installation has provided uninterrupted power flow to heavy-duty engineering workshops during grid blackouts, demonstrating how solar energy enhances operational reliability.

However, respondents gave the lowest agreement (mean = 3.80) on the statement that PV solar energy systems had reduced interruptions in teaching, training, and administrative activities. Although respondents generally agreed with the statement, the findings suggest that occasional operational disruptions still occur despite the adoption of solar energy systems. This may be attributed to the limited capacity of installed PV systems, inadequate battery storage, or continued reliance on the national electricity grid during periods of peak consumption.

Overall, the mean result of 4.12 indicates that respondents generally agreed that integrating photovoltaic solar energy has generated substantial operational benefits in Kenya National Youth Service TVET training institutions.

The interview findings revealed that the integration of photovoltaic (PV) solar energy has significantly improved the operational performance of Kenya National Youth Service (NYS) TVET training institutions. The respondents consistently emphasized that the availability of reliable solar-generated electricity has enhanced the continuity of institutional operations, particularly during periods of power outages. They noted that workshops, computer laboratories, engineering laboratories, and administrative offices continue functioning even when the national electricity grid experiences interruptions, thereby minimizing disruptions to teaching, learning, and administrative activities.

The principals and the head of departments were quoted saying:

"Solar energy has ensured that our workshops, computer laboratories, and administrative offices continue operating even when there is a power outage. This has improved the continuity of training activities." [Head of Department 3]

"Before installing the solar system, interruptions caused by electricity outages affected practical lessons. Today, students are able to continue learning without major disruptions." [Principal 2]

"Reliable electricity has improved the efficiency of our ICT laboratories and engineering workshops. Trainers can conduct practical sessions more effectively than before." [Head of Department 1]

"The solar system now powers all machines and key services within the institution, ensuring uninterrupted electricity supply with no reported blackouts. This development has enhanced training activities, assessment processes, security, and overall administrative operations." [Senior Principal, Khwisero TVC]

"Solar installation in schools is expected to enhance energy reliability, reduce operational costs and lower the institutions carbon footprint and demonstrate how renewable energy solutions can strengthen resilience in learning environment while contributing to Kenya's broader climate commitments." [KCB Kenya Managing Director]

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3.3 Discussion of Findings

3.3.1 Operational Benefits of PV Solar Energy

The findings established that integrating photovoltaic (PV) solar energy has generated substantial operational benefits in Kenya National Youth Service (NYS) TVET institutions, as reflected by the overall mean score of 4.12. Respondents agreed that PV solar energy systems have enabled institutions to operate effectively during power outages, enhanced the efficiency of workshops, laboratories, and ICT equipment, improved overall institutional performance, and increased the reliability of electricity supply. However, respondents reported relatively lower agreement that solar energy had completely eliminated interruptions in teaching, training, and administrative activities. This suggests that although PV solar energy has significantly enhanced institutional operations, occasional disruptions persist due to the limited capacity of some solar systems or continued dependence on the national electricity grid.

The findings are consistent with those of Murphy et al. (2024), who reported that solar photovoltaic systems integrated with battery storage significantly improved operational reliability in universities and public institutions in the United States. Their study found that solar energy ensured uninterrupted electricity supply during grid outages, thereby supporting continuous teaching, research, and administrative functions. Similarly, the present study established that respondents strongly agreed that PV solar energy enabled NYS TVET institutions to continue operating effectively during power outages. These findings demonstrate that solar energy enhances institutional resilience by minimizing the effects of unreliable grid electricity and ensuring continuity of essential educational activities.

The findings also agree with those reported by Rahdan et al. (2023) in Germany, who found that distributed solar photovoltaic systems improved institutional energy autonomy, enhanced load management, and reduced operational disruptions in universities. Their study concluded that on-site electricity generation enables institutions to operate more efficiently while reducing dependence on external electricity supply. Likewise, respondents in the current study agreed that integrating PV solar energy had improved the reliability of electricity supply and enhanced the overall operational performance of their institutions. This concurrence suggests that renewable energy technologies contribute significantly to improving operational efficiency by providing a stable and dependable source of electricity.

Similarly, the findings support those of Badiei and Campos do Prado (2023), whose study in Australian tertiary institutions established that aligning solar power generation with institutional energy demand improved operational efficiency and stabilized daily electricity consumption. The authors argued that reliable electricity enables institutions to optimize the use of educational facilities and resources. In the present study, respondents agreed that PV solar energy had enhanced the efficiency of operating workshops, laboratories, and ICT equipment. These findings indicate that reliable electricity supply is essential for supporting competency-based training within TVET institutions, where practical instruction depends heavily on the continuous operation of technical equipment.

The findings further corroborate those of The Alliance for Rural Electrification (2023), which found that schools in South Africa equipped with solar photovoltaic systems and battery storage experienced uninterrupted learning during periods of load shedding. The study concluded that solar energy significantly reduced operational disruptions and enhanced institutional continuity. Similarly, respondents in the current study acknowledged that solar energy systems enabled institutions to operate effectively during power outages. This suggests that PV solar energy strengthens the operational resilience of educational institutions by ensuring that teaching and administrative functions continue even during interruptions in grid electricity supply.

The results are also consistent with the findings of Olatomiwa et al. (2022), who demonstrated that hybrid solar photovoltaic systems in Nigerian tertiary institutions improved operational efficiency by providing stable electricity for laboratories, workshops, and ICT facilities. Their study emphasized that reliable energy is particularly important in technical institutions where practical learning activities require uninterrupted electricity. Likewise, the present study found that respondents agreed that PV solar energy had enhanced the efficiency of workshops, laboratories, and ICT equipment. These findings underscore the importance of renewable energy in supporting practical skills development and improving the quality of technical education.

At the regional level, the findings agree with those of the World Bank (2019), which reported that off-grid solar electrification in Rwandan schools improved institutional operations by providing reliable lighting, supporting digital learning, and extending study hours. Similarly, the Christian Science Monitor (2018) found that Uganda's Energy for Rural Transformation Project improved operational reliability in schools by providing consistent electricity for lighting and other essential services. The present study similarly established that PV solar energy has improved the reliability of electricity supply in NYS TVET institutions, thereby supporting effective institutional operations and reducing dependence on unreliable electricity sources.

The findings further support those reported by VET Toolbox (2023) in Tanzania, which established that integrating solar energy into vocational institutions enhanced the continuous operation of workshops and training equipment while improving the quality of practical instruction. Likewise, UNESCO (2022) found that solar electrification improved ICT integration and digital learning in Ethiopian schools. These findings are consistent with the current study, where respondents agreed that solar energy had enhanced the efficiency of operating workshops, laboratories, and ICT equipment. This suggests that reliable electricity is fundamental to the successful implementation of competency-based education and digital learning initiatives within TVET institutions.

At the local level, the findings are consistent with the Kenya News Agency (2025), which reported that the installation of a 350-kW solar power system at Mpesa Foundation Academy significantly enhanced operational reliability by ensuring uninterrupted electricity supply for learning and administrative activities. Similarly, Energy 4 Impact (2024) found that Project JUA improved

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operational efficiency in Kenyan schools by extending learning hours, powering essential equipment, and strengthening service delivery. Furthermore, the Ministry of Energy (2021) established that solar PV adoption in Kenyan rural schools improved lighting, facilitated ICT integration, and enhanced administrative operations. These findings closely align with the current study, which found that PV solar energy has improved institutional operations by enhancing electricity reliability and supporting the efficient functioning of teaching and administrative facilities.

Recent developments in Kenya further reinforce these findings. The KCB-Nandi County partnership to solarize public institutions aims to enhance energy reliability and strengthen resilience in learning environments. Similarly, the National TVET Solarization Initiative, spearheaded by the Ministry of Education through the State Department for TVET, focuses on five core operational milestones including energy reliability, infrastructure modernization, and climate resilience. The integration of solar PV installations as live learning projects, where trainees work alongside expert solar engineers, further demonstrates how operational benefits extend to enhancing practical training and skills development.

Despite these positive findings, the relatively lower agreement regarding the reduction of interruptions in teaching, training, and administrative activities suggests that operational challenges remain. This may be attributed to the limited capacity of installed PV systems, inadequate battery storage, increasing institutional electricity demand, or continued reliance on the national electricity grid during periods of peak consumption. These findings indicate that although PV solar energy has substantially improved institutional operations, further investment in expanding system capacity and energy storage technologies is necessary to maximize operational reliability.

4. CONCLUSION

This paper examined the operational benefits associated with integrating photovoltaic (PV) solar energy in Kenya National Youth Service (NYS) TVET training institutions. The study concludes that photovoltaic solar energy significantly enhances institutional operational performance. Reliable electricity supply has improved the operation of workshops, laboratories, ICT facilities, and administrative services while reducing the effects of frequent power interruptions. Consequently, solar energy contributes to improved quality of teaching, learning, and institutional productivity.

The study further concludes that integrating PV solar energy enables institutions to operate effectively during power outages, enhances the efficiency of practical training facilities, improves the reliability of electricity supply, and strengthens overall institutional performance. However, the finding that occasional operational disruptions persist suggests that further investment in expanding system capacity and battery storage is necessary to maximize operational reliability.

These findings support the Technology-Organization-Environment (TOE) Framework, which posits that successful adoption of technological innovations depends on technological capability, organizational readiness, and supportive institutional environments. The results also reinforce the Resource-Based View (RBV) Theory, which argues that strategic resources such as reliable renewable energy infrastructure improve organizational efficiency and create sustainable competitive advantages. Therefore, continued investment in expanding photovoltaic solar systems and complementary battery storage technologies will further strengthen the operational performance and resilience of NYS TVET training institutions.

Based on the findings and conclusions, the following recommendations are proposed:

NYS TVET institutions should progressively increase the capacity of installed photovoltaic systems and battery storage technologies to reduce dependence on the national electricity grid and maximize operational reliability during power outages.

Institutional management should continue investing in staff development through continuous professional training on the operation, maintenance, and management of photovoltaic solar energy systems. Enhancing technical competencies will improve system efficiency and sustainability.

The Kenya National Youth Service should integrate renewable energy management and energy efficiency practices into institutional strategic plans to ensure long-term sustainability and maximize the operational benefits associated with photovoltaic solar energy investments.

The government should strengthen partnerships with development partners, private sector investors, and renewable energy companies to support the installation, maintenance, and expansion of photovoltaic solar systems in NYS TVET institutions, particularly through innovative financing mechanisms that include battery storage solutions.

NYS TVET institutions should establish routine monitoring and evaluation of solar system performance to identify operational challenges and inform decisions regarding system upgrades and expansions.

Future studies should examine the contribution of battery energy storage technologies to enhancing the operational efficiency and financial viability of photovoltaic solar systems in TVET institutions. Further research should assess the technical performance and maintenance practices of photovoltaic solar energy systems and their influence on institutional energy efficiency and sustainability. A comparative study should be conducted to evaluate the effectiveness of photovoltaic solar energy systems in public and private TVET institutions in Kenya.

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