

Integrated Infrastructure, Energy Resilience and Intelligent Security Planning for Sustainable Technical Education in a Newly Established Nigerian Polytechnic: A Verified Engineering Case Study of Federal Polytechnic Ngodo Isuochi, Abia State, Nigeria

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Abstract

Technical education institutions require reliable electricity, digital infrastructure, security, maintenance, and institutional capacity to support effective practical teaching. This study evaluates the verified infrastructure, energy, and security baseline of Federal Polytechnic Ngodo - Isuochi and proposes an engineering framework for improving energy resilience, laboratory continuity, intelligent security, and institutional growth.

A single-institution engineering case-study design was adopted. Institutional facilities and equipment inventories, solar-system nameplate data, supplied load measurements, and current enrolment and staff information were analyzed using descriptive statistics, electrical capacity calculations, photovoltaic (PV) yield modelling, battery-autonomy calculations, and scenario-based sizing. No unmeasured campus-wide demand or energy consumption data were fabricated.

The institution has a 500 kVA, 11/0.415 kV transformer and three decentralized solar installations, each comprising a 10 kVA inverter and 4.8 kWp PV array, giving 14.4 kWp total PV capacity. Three 5 kWh LiFePO₄ batteries provide 15 kWh nominal storage. Identified connected loads total 16.73 kW, including administration, ICT, library, and electrical/electronic practical facilities.

Assuming 4.8 peak-sun-hours daily and a 0.78 system factor, estimated PV generation is 53.91 kWh/day. The batteries provide approximately 11.4 kWh of theoretical usable energy, offering only 0.82–1.18 hours of autonomy for the three solar-supported loads. A six-hour laboratory-support scenario requires approximately 44.29 kWh of nominal battery storage and 8.99 kWp of PV capacity.

The study proposes an Integrated Smart Technical Education and Infrastructure Resilience Framework that prioritizes critical-load integration, laboratory electrification, battery expansion, intelligent security, predictive maintenance, and data-driven infrastructure planning.

Keywords: infrastructure integration; energy resilience; renewable energy; smart campus security; technical education; sustainable infrastructure planning

1 Introduction

Technical and vocational education is fundamentally practical. In Electrical/Electronics Engineering Technology (EET), competency formation depends on repeated exposure to electrical measurements, circuit construction, machine operation, electrical installation, maintenance, electronics, communication systems, troubleshooting, and safety procedures. The National Board for Technical Education (NBTE) curriculum for the National Diploma in Electrical and Electronics Engineering Technology reflects this practical orientation through course specifications and laboratory-oriented training requirements. The current NBTE curriculum was issued in November 2024 and provides a contemporary benchmark for interpreting laboratory and infrastructure readiness.

The physical presence of laboratories, however, does not automatically translate into practical educational capacity. A laboratory containing appropriate equipment but experiencing unreliable power supply, inadequate safety systems, poor maintenance, restricted operating hours, or weak scheduling remains operationally constrained. The same principle applies to ICT facilities and administrative systems. Consequently, infrastructure readiness should be understood as a system property arising from the interaction of physical assets, electricity, digital connectivity, security, maintenance, human resources, and institutional governance.

Energy resilience is particularly important in Nigeria because educational institutions frequently operate under uncertain electricity supply conditions. The resilience literature distinguishes resilience from simple reliability by considering the capacity of a system to withstand disruption, maintain essential functions, and recover or adapt after disruptive events. Jasiūnas et al. (2021) and Ahmadi et al. (2021) show that energy resilience is threat-dependent and increasingly connected with renewable generation, storage, digitalization and cybersecurity.

University and campus microgrid research has demonstrated the value of combining PV generation, battery energy storage, and intelligent energy management. Chedid et al. (2020) investigated PV-battery redesign under unreliable grid conditions, while Chedid and Sawwas (2021) applied genetic-algorithm-based sizing and rule-based energy management to a university campus. Ajiboye et al. (2022) demonstrated the value of data-driven planning for hybrid renewable energy management in a Nigerian smart-campus context.

More recent campus microgrid research has emphasized uncertainty, demand response, distributed energy resources, battery degradation, and optimization. Muqeet et al. (2021), for example, developed an energy-management approach incorporating renewable generation, battery storage, uncertainty, and demand response.

The smart-campus literature further indicates that campus transformation should not be reduced to the deployment of isolated digital devices. Polin et al. (2023) conceptualized the smart campus as an integrated physical-digital environment, while Polin et al. (2024) emphasized assessment frameworks for smart-campus development. Kourgiouzou et al. (2021) similarly argued for holistic smart-energy pathways at campus scale.

Aghamolaei and Fallahpour (2023) identified energy systems, management and control, renewable energy, human factors, and smart technologies as important dimensions of campus decarbonization.

Security is another dimension of infrastructure resilience. As institutions introduce CCTV, access control, sensors, IoT devices and digital energy-management systems, physical and cyber-security boundaries become increasingly connected. Rajmohan et al. (2022) found that IoT security architec-

ture remains fragmented across layers, while Aversano et al. (2021) showed the growing application of deep learning to IoT security while also identifying unresolved limitations and vulnerabilities.

Federal Polytechnic Ngodo Isuochi provides an appropriate case for this integrated investigation. The institution is newly established, operates from its take-off campus while permanent-site development continues, and already possesses dedicated E/E laboratories and workshops. It also has a 500 kVA transformer and three decentralised solar installations supporting administration, ICT and library loads. The central engineering problem is therefore how to integrate these existing assets with practical laboratory power, security, maintenance, and future institutional expansion.

This study makes five contributions. First, it establishes a verified engineering baseline using actual installed-system information rather than hypothetical campus assumptions. Second, it distinguishes measured connected loads from total campus demand. Third, it corrects and explicitly quantifies the very limited present battery-storage capacity. Fourth, it develops a scenario-based PV and battery sizing pathway for practical-laboratory continuity. Fifth, it integrates energy, laboratory, security, enrolment, and governance dimensions into an optimization-ready framework for sustainable technical education.

2 Literature review

2.1 Energy-system resilience and educational continuity

Jasiūnas et al. (2021) reviewed energy-system resilience as the ability of energy systems to withstand disruptive events and recover while maintaining essential functions. Their review is relevant to educational campuses because resilience depends on the interaction between the energy system and its threat environment. Ahmadi et al. (2021) further reviewed quantitative indicators and modelling approaches for resilience assessment. The implication is that campus resilience should be expressed through measurable variables such as critical-load coverage, storage duration, renewable contribution, recovery capability, and infrastructure redundancy.

Campus microgrid studies provide a direct engineering basis. Chedid et al. (2020) showed that PV and battery storage can redesign campus power systems operating under unreliable grid conditions. Chedid and Sawwas (2021) demonstrated a techno-economic planning approach using genetic-algorithm-based sizing and rule-based energy management. These studies support PV-battery systems as resilience assets but also indicate that sizing must be connected to actual load behaviour.

Ajiboye et al. (2022) provide an important Nigerian reference. Their study of hybrid renewable-energy management in a smart-campus environment demonstrates the value of detailed load and resource analysis and sensitivity analysis. Ondachi (2024), using the University of Abuja as a Nigerian case study, similarly shows the relevance of hybrid renewable systems for institutional electricity supply and the usefulness of simulation-based optimization.

However, the scale of those studies differs from the present case, which is a smaller polytechnic with a verified decentralized PV installation and a relatively modest identified load.

2.2 Smart-campus planning

Polin et al. (2023) reviewed smart-campus development and emphasized the campus as a living laboratory in which digital technologies can support teaching, research, operations, and sustainability. Polin et al. (2024) subsequently developed an assessment framework for smart-campus maturity.

These studies indicate that a smart campus should be assessed across multiple dimensions rather than by counting digital devices.

Kourgiozou et al. (2021) reviewed smart-energy systems in higher education and proposed a holistic decision-making perspective for integrating multiple energy vectors at campus scale. Ali et al. (2023) reviewed campus prosumer microgrids, energy-management architectures, storage technologies, and simulation tools, emphasizing that distributed generation and storage require effective energy-management strategies to become economically and operationally useful.

Oğuz and Güğül (2024) provide another useful insight: campus-level and building-level renewable-energy configurations can lead to materially different system sizes and performance outcomes. Their finding supports the present study's argument that decentralised solar installations should not automatically be assumed to constitute an optimized campus microgrid. The location of generation and storage relative to critical loads matters.

2.3 Decarbonization and sustainability

Aghamolaei and Fallahpour (2023) reviewed university-campus decarbonization strategies and identified renewable energy, energy systems, management and control, human factors, and smart technologies among the relevant dimensions. Kourgiozou et al. (2021) similarly linked smart energy systems to longer-term net-zero pathways.

For Nigeria, Kamil et al. (2021) demonstrated through hybrid renewable-resource modelling that renewable-energy hybridization can provide substantial annual energy production relative to estimated institutional loads. Such work supports the feasibility of renewable-energy deployment in the Nigerian context but also reinforces the need for site-specific load and resource data.

2.4 Intelligent security and IoT

Rajmohan et al. (2022) systematically reviewed IoT security patterns and architectures and found limited integration across the layers of IoT systems. Aversano et al. (2021) reviewed 69 studies on deep learning for IoT security and identified both opportunities and limitations. The literature therefore supports intelligent surveillance, anomaly detection, and sensor-based security but cautions that adding connected devices without a security architecture can introduce new vulnerabilities.

For a polytechnic, security has two simultaneous dimensions: protection of people and assets, and protection of the digital infrastructure that increasingly controls energy and security systems. A resilient smart-campus design should therefore include physical surveillance, access control, lighting, data governance, network segmentation, authentication and cyber-incident response.

2.5 Synthesis of the literature

The verified literature converges on four propositions: (1) resilience is a system-level property rather than a single technology, (2) campus renewable-energy systems perform best when supported by demand measurement and energy-management strategies, (3) smart-campus development requires integrated physical, digital, and governance dimensions, and (4) security must be designed across both physical and cyber layers.

The unresolved issue is how these principles should be translated into a newly established Nigerian polytechnic in which physical infrastructure exists, but energy support is spatially fragmented,

laboratory loads are outside the installed solar boundary, battery storage is limited, enrolment is still developing, and security infrastructure is incomplete.

This is the specific problem addressed by the present study.

3 Research gap

Three principal gaps are identified.

1. **Energy Infrastructure Integration Gap:** Most campus energy studies focus on designing or optimizing energy systems from hypothetical baselines, with limited attention to institutions that have partially deployed renewable energy assets that are not yet integrated with practical laboratories.
2. **Institutional and Contextual Gap:** Existing smart-campus studies primarily focus on established universities and technologically advanced campuses, with limited research on newly established Nigerian polytechnics where practical training, accreditation readiness, security, staff capacity, and energy resilience must develop simultaneously.
3. **Integrated Engineering Planning Gap:** Few studies combine verified laboratory infrastructure, measured connected electrical load, existing solar photovoltaic (PV) and battery energy storage system (BESS) configurations, student enrolment, and physical-security readiness within a unified engineering planning framework.

4 Research questions and analytical hypotheses

- RQ1. What are the verified infrastructure, electrical energy, and security baseline of Federal Polytechnic Ngodo Isuochi?
- RQ2. How much practical laboratory-connected load is currently outside the installed solar-energy supply boundary?
- RQ3. What is the present theoretical storage autonomy of the installed battery configuration?
- RQ4. What PV and battery capacities would be required under a defined laboratory-continuity scenario?
- RQ5. How can energy resilience, laboratory readiness, security, and institutional growth be represented within a unified optimization framework?
- RQ6. What infrastructure and policy interventions can improve the institution's readiness for sustainable growth and future accreditation?

4.1 Analytical hypotheses

- **H1:** The institution's principal infrastructure challenge is integration and operational continuity rather than complete absence of physical infrastructure.
- **H2:** The existing battery configuration provides materially shorter autonomy than would be inferred from the PV and inverter nameplate capacities alone.
- **H3:** Integrating the E/E laboratories into a critical-load renewable-energy architecture would substantially improve practical-training resilience.
- **H4:** A staged, data-driven infrastructure strategy is more technically defensible than attempting to expand all infrastructure categories simultaneously.

Because this is a single-institution case study without repeated experimental observations or a multi-campus sample, the hypotheses are treated as analytical propositions and engineering hypotheses. Inferential significance testing is not claimed.

5 Methodology

5.1 Research design

A mixed descriptive-engineering case-study methodology was adopted. The study combines documentary verification, engineering calculations, scenario modelling, infrastructure assessment, and optimization formulation. The research does not claim experimental performance measurements where none were supplied.

The evidence hierarchy is: (1) verified nameplate or installed-system information; (2) institutional facility and equipment records; (3) supplied measured connected-load values; (4) calculated engineering quantities derived directly from verified values; and (5) scenario-based assumptions used solely for planning. This hierarchy prevents calculated values from being misrepresented as measured field observations.

5.2 Data sources

The study used the institutional physical-facilities and Electrical and Electronic Engineering equipment inventory; installed transformer information; installed PV module and inverter information; battery nameplate information; measured connected-load values for identified buildings and laboratories; institutional enrolment and staffing information; verified information concerning existing security facilities; contemporary peer-reviewed literature; and the 2024 NBTE ND Electrical and Electronics Engineering Technology curriculum (National Board for Technical Education, 2024).

5.3 Analytical tools

The analysis uses algebraic electrical calculations, descriptive statistics, scenario modelling, and a multi-objective optimization formulation.

The optimization model is presented as an engineering decision model rather than as a falsely claimed computational optimum because complete time-series load, solar irradiance, tariff, equipment-cost, and maintenance-cost datasets were not available.

6 Institutional case-study description

Federal Polytechnic Ngodo Isuochi is a newly established Nigerian polytechnic operating from its take-off campus while permanent-site development continues. The institution currently has 400 staff, comprising 215 academic and 185 non-academic staff. The current student population for this study is 118.

Programmes include Accountancy, Business Administration/Management, Computer Science, Computer Engineering Technology, Electrical/Electronics Engineering Technology, Science Laboratory Technology and Statistics. All listed programmes are National Diploma programmes of two-year full-time duration in the institutional programme record.

The 2025/2026 Electrical and Electronic Engineering Technology enrolment supplied for the present study is two ND1 students and zero ND2 students. Computer Engineering Technology has one ND2 student. These values indicate that the institution remains in an early enrolment-growth phase.

The institutional facilities record identifies two programme-exclusive classrooms of 54 m² each with a capacity of 40, one exclusive 200 m² lecture theatre/hall with a capacity of 150, three shared 54 m² classrooms, and one shared 120 m² lecture hall. Dedicated E/E facilities comprise five 120 m² laboratories/workshops, each with a stated capacity of 30 students:

- Basic Electricity/Measurement and Instrumentation Laboratory
- Electronics/Telecommunications Laboratory
- Electrical Power and Machines Laboratory
- Electrical Installation/Maintenance and Repair Workshop
- Electronic Workshop

The inventory further records substantial laboratory equipment. The Basic Electricity/Measurement and Instrumentation Laboratory includes multiple ammeters, voltmeters, wattmeters, Megger testers, Wheatstone bridges, potentiometers, electronic trainers, oscilloscopes, oscillators, rheostats, earth-loop testers, and multimeters. The Power and Machines Laboratory contains transformers, power meters, transmission/distribution-line trainers, DC and AC machines, starters, dynamometer sets, transformer trainers, variable R/L/C loads and a machine-control trainer. The installation workshop contains wiring boards, drills, electrician tool kits, conduit-bending equipment, ELCBs, cable-jointing equipment, earth rods, cables, trunking equipment, Megger testers and maintenance equipment. The electronic and communications facilities include semiconductor trainers, transmitters/receivers, oscilloscopes, signal generators, IC/transistor testers, power supplies, amplifiers and circuit-construction trainers.

The facility inventory therefore supports the central premise of this study: the institution has meaningful physical and practical infrastructure, but its operational resilience depends on energy, maintenance, security and integration.

7 Infrastructure assessment

7.1 Physical infrastructure

The Electrical and Electronic Engineering Technology programme has five dedicated practical facilities of 120 m² each, giving a combined dedicated laboratory/workshop area of 600 m². At a nominal capacity of 30 students per facility, the combined stated capacity is 150 student places. However, simultaneous utilization is constrained by equipment availability, scheduling, safety and power.

The existence of the facilities is therefore not itself evidence of full operational readiness. The engineering assessment distinguishes asset presence from functional readiness.

7.2 Laboratory equipment readiness

The inventory indicates that most listed equipment is recorded as being in good condition. This is a strong baseline for a newly established technical programme.

However, the inventory is primarily an asset record and does not provide measured utilization rates, calibration histories, preventive-maintenance records or practical-session energy profiles.

Accordingly, this study classifies equipment availability as documented rather than experimentally verified operational performance.

7.3 Infrastructure readiness framework

A practical readiness vector is defined as:

$$R_I = [R_P, R_E, R_L, R_{ICT}, R_S, R_M, R_G] \quad (1)$$

where R_P represents physical infrastructure, R_E energy resilience, R_L laboratory readiness, R_{ICT} digital infrastructure, R_S security readiness, R_M maintenance readiness and R_G governance/accreditation readiness. The components are not assigned unsupported numerical scores. A future audit can score each component on a 0–1 or 0–100 scale using independently defined criteria.

8 Energy modelling

8.1 Transformer

The installed transformer is a MEKSAN 500 kVA, three-phase, 50 Hz distribution transformer with a primary voltage of 11 kV, a secondary voltage of 415/240 V (voltage ratio 11/0.415 kV), vector group Dyn11, a secondary full-load current of approximately 695.6 A and a primary full-load current of approximately 26.24 A. The theoretical secondary full-load current is:

$$I_L = \frac{S}{\sqrt{3}V_{LL}} = \frac{500000}{\sqrt{3} \times 415} \approx 695.6A \quad (2)$$

This agrees with the supplied nameplate secondary current. The transformer rating should not be interpreted as actual campus demand or utilization. The presently identified connected load of 16.73 kW represents only the loads captured in this study.

8.2 Existing PV architecture

Each of the three solar sites has 16×300 W JinkoSolar PV modules, one 10 kVA inverter, and one 5 kWh, 51.2 V LiFePO₄ battery. The PV capacity per site is:

$$P_{PV,site} = 16 \times 0.300 = 4.8 \text{ kWp} \quad (3)$$

The total PV capacity is:

$$P_{PV,total} = 3 \times 4.8 = 14.4 \text{ kWp} \quad (4)$$

The total inverter nameplate capacity is:

$$S_{INV,total} = 3 \times 10 = 30 \text{ kVA} \quad (5)$$

8.3 Battery architecture

The battery nameplate identifies the Felicitysolar LPBF48100-M as a 51.2 V, 5 kWh lithium iron phosphate (LiFePO₄) battery, with a recommended charge/discharge power of 2.56 kW and scalability of up to eight units in parallel. Only one battery is installed per 10 kVA inverter. Therefore:

$$E_{B,site} = 1 \times 5 = 5 \text{ kWh} \quad (6)$$

$$E_{B,total} = 3 \times 5 = 15 \text{ kWh} \quad (7)$$

The installed battery-to-inverter ratio is:

$$\frac{E_B}{S_{INV}} = \frac{15}{30} = 0.5 \text{ kWh/kVA} \quad (8)$$

The battery's recommended charge/discharge power is:

$$P_B = 1 \times 2.56 = 2.56 \text{ kW per site} \quad (9)$$

This creates an important engineering constraint: the 2.56 kW recommended battery power is substantially below the 10 kVA inverter nameplate. The inverter may therefore not be able to draw its full AC nameplate power from the single battery without violating battery operating recommendations.

The exact permissible operating point must be confirmed against the inverter DC-input current, inverter battery-voltage range, battery-BMS compatibility, maximum continuous battery current, transient requirements, manufacturer-approved parallel configuration, and warranty conditions. This is an important finding that should be verified before any future battery expansion or inverter reconfiguration.

8.4 Measured connected loads

The measured loads of the solar-supported buildings are 4.64 kW (administration), 3.25 kW (ICT) and 3.23 kW (library). Therefore:

$$P_{\text{solar-supported}} = 4.64 + 3.25 + 3.23 = 11.12 \text{ kW} \quad (10)$$

The five Electrical and Electronic Engineering laboratory loads are:

- Power and Machines Laboratory: 1.46 kW
- Installation/Maintenance/Repair Workshop: 1.28 kW
- Electronic Workshop: 0.97 kW
- Basic Electricity/Masurement and Instrumentation Laboratory: 1.11 kW
- Electronics/Telecommunications Laboratory: 0.79 kW

Therefore:

$$P_{\text{lab}} = 1.46 + 1.28 + 0.97 + 1.11 + 0.79 = 5.61 \text{ kW} \quad (11)$$

The presently identified connected load is:

$$P_{\text{identified}} = 11.12 + 5.61 = 16.73 \text{ kW} \quad (12)$$

The laboratory load represents:

$$\frac{5.61}{16.73} \times 100 = 33.53\% \quad (13)$$

of the identified load, and the solar-supported buildings account for:

$$\frac{11.12}{16.73} \times 100 = 66.47\% \quad (14)$$

These percentages describe only the identified loads captured in this study; they are not campus-wide energy shares.

9 PV sizing

9.1 Existing PV yield

A planning estimate is used to illustrate the energy scale of the existing PV system. Because measured irradiance and inverter output data were not supplied, a peak-sun-hours assumption of 4.8 h/day and a system factor of 0.78 are adopted.

$$E_{PV,day} = P_{PV} \times H_{PSH} \times \eta_{sys} = 14.4 \times 4.8 \times 0.78 \approx 53.91 \text{ kWh/day} \quad (15)$$

The corresponding annual planning yield is approximately:

$$E_{PV,year} = 53.91 \times 365 \approx 19.68 \text{ MWh/year} \quad (16)$$

This is a modelled planning estimate, not a measured annual generation value.

9.2 Laboratory-support PV scenario

To provide a transparent engineering scenario, assume the five E/E practical facilities require their measured connected load for six hours per operational day.

$$E_{lab,day} = 5.61 \times 6 = 33.66 \text{ kWh/day} \quad (17)$$

The PV capacity required to supply this daily energy under the same planning assumptions is:

$$P_{PV,lab} = \frac{E_{lab,day}}{H_{PSH}\eta_{sys}} = \frac{33.66}{4.8 \times 0.78} \approx 8.99 \text{ kWp} \quad (18)$$

At 300 W per module:

$$N_{PV} = \frac{8.99}{0.30} \approx 29.97 \quad (19)$$

Therefore, approximately $30 \times 300 \text{ W}$ modules, equivalent to 9.0 kWp, constitute a useful first-order planning configuration for six-hour daily laboratory-energy support under the stated assumptions.

This is not a final procurement design because laboratory schedules, motor starting currents, actual solar resource, wiring losses and battery charging requirements must be incorporated during detailed design.

10 Battery sizing

10.1 Present theoretical delivered energy

Assuming 80% usable depth of discharge (DoD) and 95% battery-side efficiency:

$$E_{B,delivered,site} = 5 \times 0.80 \times 0.95 = 3.80 \text{ kWh} \quad (20)$$

For the three installed batteries:

$$E_{B,delivered,total} = 15 \times 0.80 \times 0.95 = 11.40 \text{ kWh} \quad (21)$$

10.2 Present theoretical autonomy

The theoretical autonomy at the measured loads of the administration, ICT and library buildings is:

$$T_{\text{Admin}} = \frac{3.80}{4.64} \approx 0.82\text{h} \quad (22)$$

$$T_{\text{ICT}} = \frac{3.80}{3.25} \approx 1.17\text{h} \quad (23)$$

$$T_{\text{Library}} = \frac{3.80}{3.23} \approx 1.18\text{h} \quad (24)$$

A purely mathematical pooled-storage reference gives:

$$T_{\text{Pooled}} = \frac{11.40}{11.12} \approx 1.03\text{h} \quad (25)$$

However, the pooled value must not be interpreted as actual cross-campus autonomy, because the three battery systems are decentralised and are not physically paralleled.

10.3 Six-hour laboratory battery scenario

For six hours of full connected laboratory load:

$$E_{\text{lab,6h}} = 5.61 \times 6 = 33.66 \text{ kWh} \quad (26)$$

The nominal battery capacity required at 80% DoD and 95% battery-side efficiency is:

$$E_{\text{B,nominal}} = \frac{33.66}{0.80 \times 0.95} \approx 44.29 \text{ kWh} \quad (27)$$

Using 5 kWh battery modules:

$$N_{\text{B}} = \frac{44.29}{5} \approx 8.86 \quad (28)$$

Therefore, a minimum planning quantity of approximately nine 5 kWh batteries (45 kWh nominal storage) would be required for a six-hour full-connected-load laboratory scenario under the stated assumptions. This is a planning scenario, not a recommendation to place nine batteries on one inverter. The final architecture should distribute batteries and loads according to inverter DC limits, BMS requirements, laboratory feeder topology, motor starting requirements and manufacturer-approved parallel configurations.

11 Security assessment

The verified security baseline includes perimeter fencing, a main gate, a back gate that is normally closed, one security post at the main gate and approximately 15–30 security personnel based on the institutional information supplied. Only one CCTV camera is presently identified, and it monitors the solar installation at the ICT unit.

No comprehensive internal perimeter-lighting system has been identified. No electronic access-control system or formal visitor-registration system has been identified. The institution also has no documented comprehensive campus-wide intelligent surveillance architecture in the data supplied for this study.

A Security Readiness Index (SRI) is therefore proposed:

$$SRI = w_C C + w_L L + w_A A + w_V V + w_P P + w_N N \quad (29)$$

where C is CCTV coverage, L lighting coverage, A access-control maturity, V visitor-management maturity, P perimeter protection and N network/cybersecurity readiness, and $w_C \dots w_N$ are their weights. The weights must be established during a formal security audit rather than assumed in this study.

The recommended intelligent-security architecture should include perimeter CCTV coverage, solar-powered or protected security lighting, controlled main entrance, visitor registration, staff/student identification, network segmentation for security devices, centralized event logging, intrusion/anomaly detection, backup power for security equipment, and defined physical and cyber incident-response procedures.

The design should follow a defence-in-depth principle. Increasing connected cameras and sensors without secure network architecture would create additional cyber exposure.

12 Engineering diagrams

Figures 1–6 show the existing and proposed engineering configurations.

Figure 1 shows the supply from the EEDC grid through the MEKSAN 500 kVA, 11/0.415 kV, Dyn11 transformer to the main distribution board, and the three existing independent solar branches: administration (16×300 W PV $\rightarrow$ 10 kVA inverter $\leftrightarrow$ 1 $\times$ 5 kWh/51.2 V LiFePO₄ battery $\rightarrow$ 4.64 kW load), ICT (the same configuration $\rightarrow$ 3.25 kW load) and library (the same configuration $\rightarrow$ 3.23 kW load). It also shows the Electrical and Electronic Engineering laboratories separately as a proposed critical-load feeder with 5.61 kW identified load, proposed PV/BESS, a temporary 80 kVA generator, ATS/changeover, protection, earthing, an energy meter and a future EMS connection.

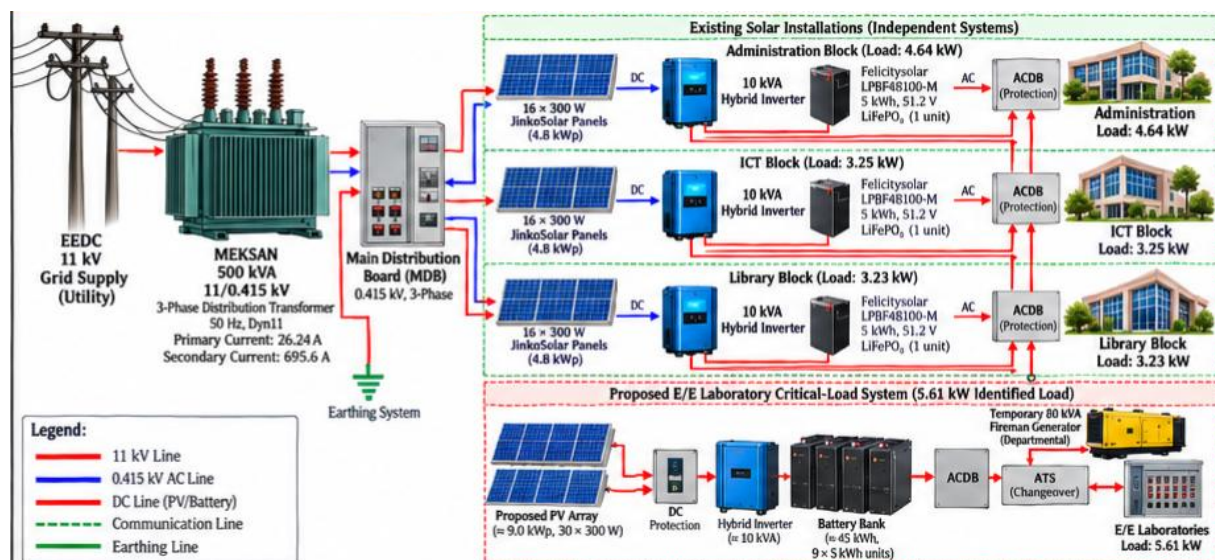


Figure 1. Campus single-line diagram showing the existing solar installations and the proposed laboratory critical-load integration (Source: Authors, 2026).

Figure 2 shows the PV subsystem of each site: 16 $\times$ 300 W JinkoSolar modules in two strings, combiner, DC isolator, DC surge protection device, MPPT/hybrid inverter interface, earthing and 4.8 kWp output. The three identical site configurations are shown side by side.

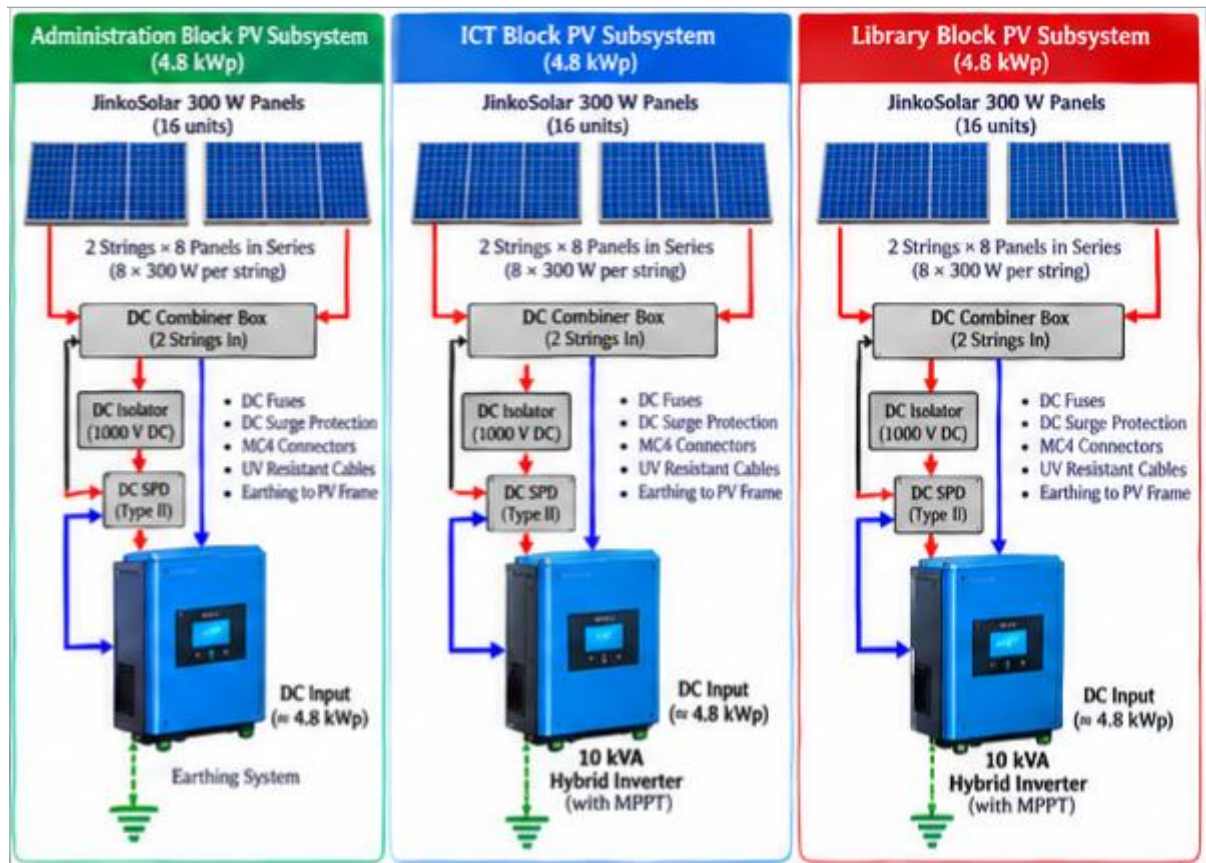


Figure 2. PV subsystem configuration for each site (4.8 kWp, 16 x 300 W) (Source: Authors, 2026).

Figure 3 shows one Felicitysolar LPBF48100-M battery (51.2 V, 5 kWh, recommended 2.56 kW charge/discharge power) with BMS, RS485/CAN communication, DC protection, isolator, inverter DC terminals and earthing. It also shows a dashed future expansion path for additional parallel batteries, subject to manufacturer limits and inverter compatibility.

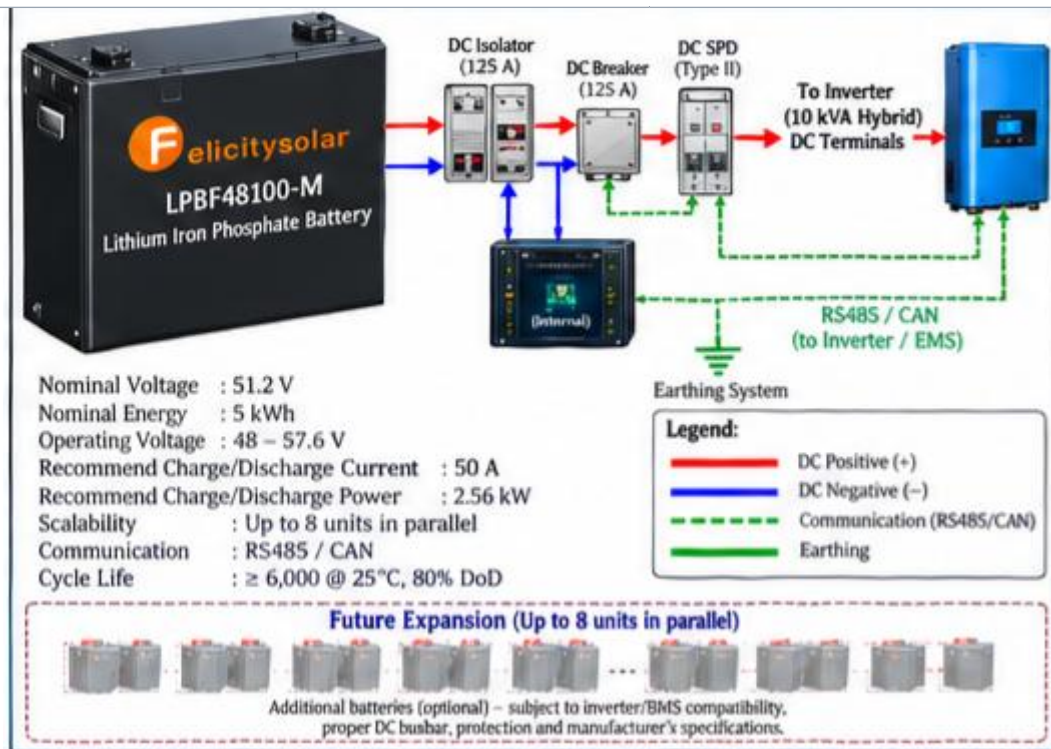


Figure 3. Battery energy storage subsystem (single battery per inverter) (Source: Authors, 2026).

Figure 4 shows the proposed laboratory critical-load microgrid: PV → DC protection → MPPT/hybrid inverter → BESS → AC distribution board → ATS/changeover → laboratory critical-load feeder, with branches to the Electrical Power and Machines Laboratory, the Electrical Installation/Maintenance/Repair Workshop, the Electronic Workshop, the Basic Electricity/Masurement and Instrumentation Laboratory and the Electronics/Telecommunications Laboratory. It also shows the temporary 80 kVA generator as emergency backup, with electrical interlocks, breakers, SPDs, earthing, an energy meter and the EMS controller.

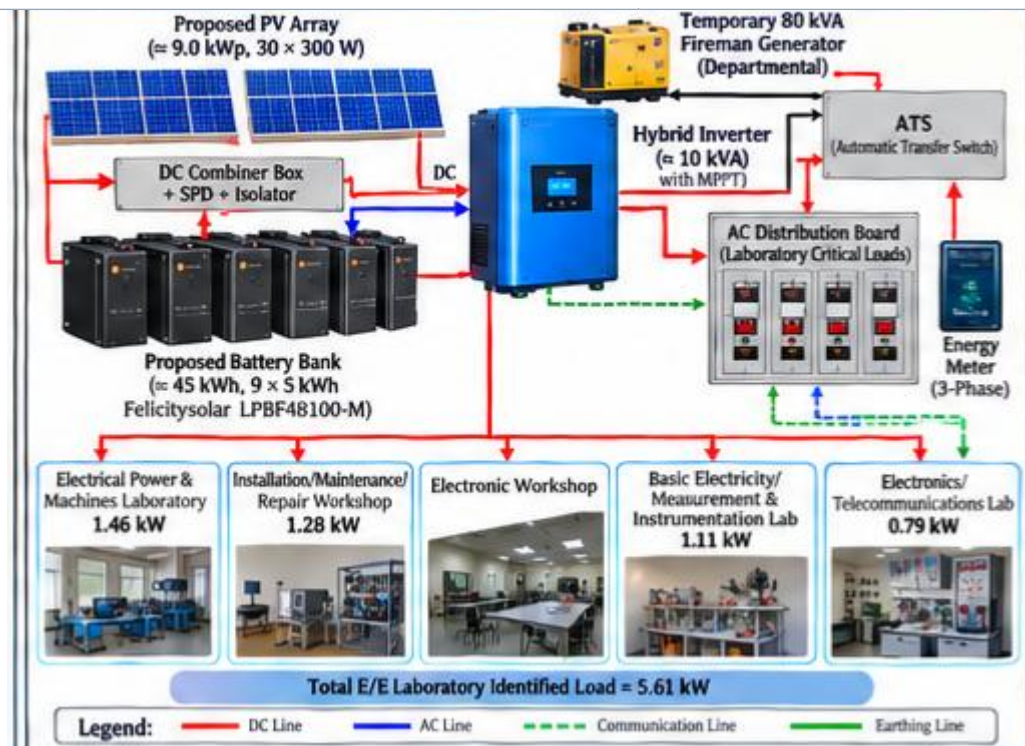


Figure 4. Proposed E/E laboratory critical-load microgrid configuration (Source: Authors, 2026).

Figure 5 shows the proposed intelligent security architecture: perimeter CCTV → PoE/network switch → firewall/VLAN → central monitoring server, together with the gate camera, access control, visitor registration, security lighting, edge AI/anomaly detection, backup power, secure network and event logging.

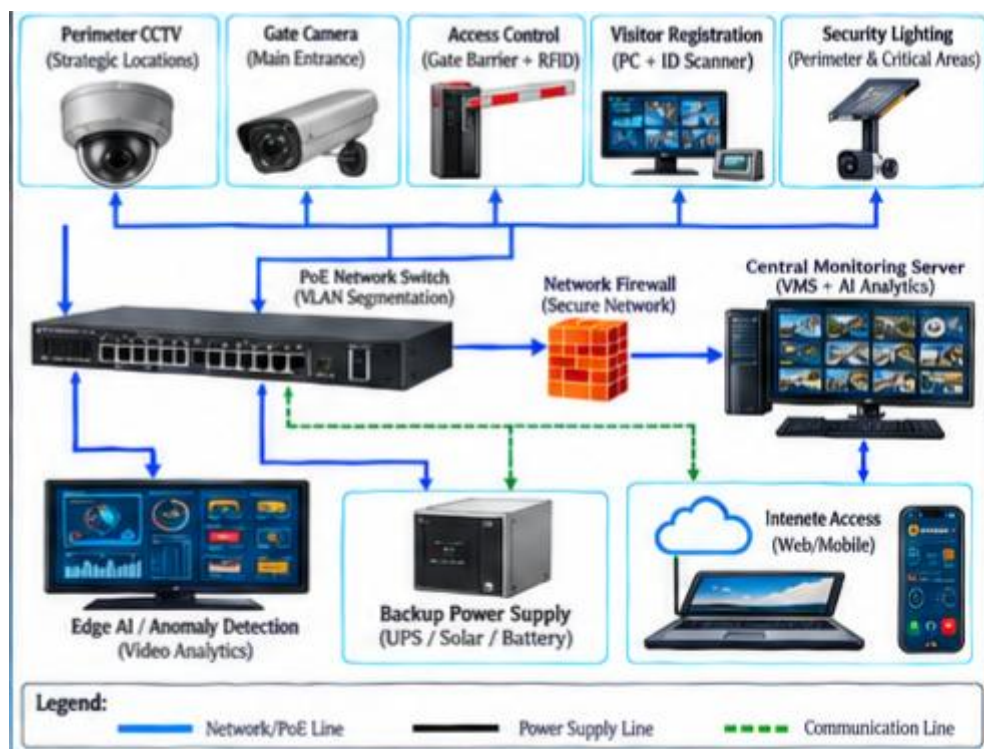


Figure 5. Intelligent security architecture for the campus (Source: Authors, 2026).

Figure 6 shows the eight connected layers of the proposed Integrated Smart Technical Education and Infrastructure Resilience Framework (ISTEIRF): (1) physical infrastructure, (2) energy resilience, (3) laboratory readiness, (4) ICT/digital infrastructure, (5) intelligent security, (6) maintenance/asset management, (7) data analytics/AI and (8) governance/accreditation. All layers converge on sustainable technical education and institutional resilience.



Figure 6. Integrated Smart Technical Education and Infrastructure Resilience Framework (ISTEIRF) (Source: Authors, 2026).

13 Enrolment analysis

The institution currently has 118 students. The Electrical and Electronic Engineering Technology programme has two ND1 students and no ND2 students in the 2025/2026 information supplied. Computer Engineering Technology has one ND2 student.

The current Electrical and Electronic Engineering Technology enrolment therefore indicates a very early programme-growth stage. This has two implications. First, the present student count should not be used as evidence that the existing laboratory capacity is unnecessary. Technical education requires infrastructure before enrolment reaches its mature level, and accreditation and programme attractiveness depend partly on credible practical facilities. Second, current low utilization means that infrastructure planning should be scalable. Oversizing every infrastructure component for a hypothetical future population may impose unnecessary capital cost, while failing to provide reliable power and security could suppress future enrolment.

The institutional programme inventory for 2024/2025 also records enrolment in several other ND programmes, but parts of the extracted table are not sufficiently aligned to assign every displayed number confidently to a specific programme. Accordingly, only the current verified aggregate and clearly identified programme values are used for quantitative analysis.

14 Statistical analysis

Because the study is a single institutional case with limited repeated observations, descriptive statistics are more defensible than inferential testing. The verified institutional indicators are given in Table 1.

Table 1. Verified institutional indicators.

Indicator	Value
Total staff	400
Academic staff	215
Non-academic staff	185
Current student population	118
Transformer capacity	500 kVA
Total PV capacity	14.4 kWp
Total inverter capacity	30 kVA
Total nominal battery storage	15 kWh
Identified connected load	16.73 kW
E/E laboratory connected load	5.61 kW

Academic staff constitute 53.75% of total staff, while non-academic staff constitute 46.25%. The student-to-total-staff ratio is approximately 0.295 students per staff member based on the supplied current counts. This unusual ratio is characteristic of an early-stage institution and should not be interpreted as an institutional efficiency indicator.

The identified Electrical and Electronics laboratory load represents 33.53% of the presently captured connected load. This is important because one-third of the identified load is associated directly with practical engineering facilities, yet those laboratories are outside the installed solar-energy boundary.

The 16.73 kW identified load is only 3.35% of the 500 kVA transformer rating. This is a screening comparison and not a transformer utilization factor because the campus-wide connected load and actual demand profile have not been fully measured.

15 Integrated optimization model

The proposed model treats campus infrastructure planning as a multi-objective decision problem. Let the decision vector be:

$$x = [P_{PV}, E_B, P_{INV}, N_L, N_C, N_{Light}, N_{Access}] \quad (30)$$

where P_{PV} is the installed PV capacity, E_B the battery capacity, P_{INV} the inverter capacity, N_L the laboratory-energy capacity, N_C the number of CCTV units, N_{Light} the number of security-lighting units and N_{Access} the number of access-control units. The conceptual objective function is:

$$\min J = w_1 C_{\text{annual}} + w_2 E_{\text{unserved}} + w_3 E_{\text{emission}} + w_4 R_{\text{penalty}} + w_5 S_{\text{penalty}} \quad (31)$$

where C_{annual} is the annualized infrastructure and operating cost, E_{unserved} the energy not supplied to critical loads, E_{emission} the associated operational emissions, R_{penalty} the resilience deficit, S_{penalty} the

security-readiness deficit and $w_1 \dots w_5$ are stakeholder-defined weights. The power balance is expressed as:

$$P_{PV}(t) + P_{grid}(t) + P_{BESS,dis}(t) + P_{gen}(t) = P_{load}(t) + P_{BESS,ch}(t) + P_{loss}(t) \quad (32)$$

The battery state of energy is represented by:

$$E_B(t+1) = E_B(t) + \eta_{ch} P_{BESS,ch}(t) \Delta t - \frac{P_{BESS,dis}(t) \Delta t}{\eta_{dis}} \quad (33)$$

The battery constraints include:

$$0 \leq E_B(t) \leq E_{B,max} \quad (34)$$

$$0 \leq P_{BESS,ch}(t) \leq P_{ch,max} \quad (35)$$

$$0 \leq P_{BESS,dis}(t) \leq P_{dis,max} \quad (36)$$

The critical-load reliability (LCR) can be represented by:

$$LCR = \frac{E_{critical,served}}{E_{critical,demand}} \quad (37)$$

A practical resilience target may then be specified as:

$$LCR \geq LCR_{min} \quad (38)$$

The model can impose a laboratory-priority constraint during grid outages:

$$P_{lab,served}(t) \geq P_{lab,critical}(t) \quad (39)$$

Security readiness can be incorporated as a minimum constraint:

$$SRI \geq SRI_{min} \quad (40)$$

The optimization can subsequently be implemented using MILP, MINLP, genetic algorithms, particle swarm optimization or other suitable methods once time-series load, solar irradiance, tariff, equipment costs and reliability data become available. The present paper deliberately does not claim a numerical economic optimum because those data were not supplied.

16 Results

16.1 Verified energy-system baseline

The verified installed system comprises 14.4 kWp PV, 30 kVA total inverter capacity and 15 kWh nominal battery storage. The architecture is decentralized across administration, ICT and library buildings. The existing energy architecture is summarized in Table 2.

Table 2. Existing energy architecture.

Location	PV	Inverter	Battery	Measured load
Administration	4.8 kWp	10 kVA	5 kWh	4.64 kW
ICT	4.8 kWp	10 kVA	5 kWh	3.25 kW

Location	PV	Inverter	Battery	Measured load
Library	4.8 kWp	10 kVA	5 kWh	3.23 kW
Total	14.4 kWp	30 kVA	15 kWh	11.12 kW

16.2 Laboratory energy gap

The connected loads of the five Electrical and Electronic Engineering practical facilities are given in Table 3.

Table 3. Electrical and Electronic Engineering practical-facility loads.

Facility	Connected load
Electrical Power & Machines Laboratory	1.46 kW
Electrical Installation/Maintenance/Repair Workshop	1.28 kW
Electronic Workshop	0.97 kW
Basic Electricity/Masurement & Instrumentation Laboratory	1.11 kW
Electronics/Telecommunications Laboratory	0.79 kW
Total	5.61 kW

The five facilities are not currently powered by the installed solar systems. Their operational energy pathway is therefore structurally different from that of administration, ICT and the library.

16.3 Storage autonomy

The corrected single-battery architecture changes the resilience interpretation substantially. The installed battery at each site provides only about 3.8 kWh of theoretically deliverable energy under the adopted assumptions. This corresponds to less than 1.2 hours at each measured site load.

The implication is not that the installed solar system is ineffective. Rather, PV generation and battery storage perform different functions. The present system has meaningful PV generation capacity but relatively small storage capacity. It is therefore better characterized as a renewable-energy-supported system with limited short-duration storage rather than a long-duration backup system.

16.4 PV generation scenario

The 14.4 kWp PV system yields approximately 53.91 kWh/day under the stated planning assumptions. This is more than the 33.66 kWh/day scenario energy requirement of the five laboratories at 5.61 kW for six hours. However, this comparison does not prove that the existing PV system can supply the laboratories because the generation is spatially distributed, the laboratories are not presently connected to the PV systems, generation is time-varying and storage is limited.

16.5 Future laboratory sizing scenario

The six-hour laboratory scenario requires approximately 8.99 kWp PV and 44.29 kWh nominal battery storage. A practical first-order configuration is approximately 9.0 kWp PV and 45 kWh nominal battery storage, subject to detailed electrical design.

This scenario indicates that laboratory electrification is technically feasible within a moderate expansion of the existing renewable-energy architecture. It also indicates that battery storage, rather than PV nameplate alone, is the more immediate resilience constraint.

17 Discussion against international literature

The results are consistent with the resilience literature in one important respect: the institution's energy problem cannot be solved by looking only at installed generation capacity.

Jasiūnas et al. (2021) emphasize that resilience depends on the system and the disruption. In the present case, the system contains a 500 kVA transformer and 14.4 kWp of PV, yet practical laboratories remain vulnerable because the laboratories are outside the solar supply boundary and battery capacity is limited.

The corrected battery configuration also illustrates why nameplate-based resilience assessments can be misleading. The total PV capacity is 14.4 kWp and inverter capacity is 30 kVA, but only 15 kWh of nominal storage is installed. The resulting 0.5 kWh/kVA battery-to-inverter ratio is low for long-duration backup.

This is consistent with the broader campus-microgrid literature, which treats storage sizing and energy-management strategy as critical elements rather than secondary additions.

The findings align with Chedid et al. (2020), who demonstrated the value of PV-battery systems under unreliable grid conditions. However, the present study extends that logic by identifying a spatial integration problem: existing PV and batteries serve administrative, ICT and library loads while practical engineering laboratories remain outside the renewable-energy boundary.

Ajiboye et al. (2022) emphasized data-driven campus energy planning. The present study supports this principle but also shows the importance of data hierarchy. Before an optimization algorithm is applied, the installed equipment configuration must be verified. The battery correction in this study changed the calculated storage capacity from an initially assumed 90 kWh to the verified 15 kWh. This is an important methodological lesson for institutional energy research.

Oğuz and Güğül (2024) demonstrated that campus-level and building-level renewable configurations can lead to different sizing outcomes. The decentralized architecture at Ngodo Isuochi illustrates this issue directly. Each site operates independently, which simplifies local deployment but limits energy sharing. A future campus microgrid could improve flexibility if interconnection is technically and economically justified.

The smart-campus findings also agree with Polin et al. (2023, 2024). A smart campus should not be defined by CCTV cameras, IoT devices or digital dashboards alone. The present case requires a coordinated physical-digital architecture involving energy, laboratory operation, security, maintenance and governance.

The security findings are consistent with Rajmohan et al. (2022) and Aversano et al. (2021). A future intelligent-security system should not simply increase the number of cameras. It should establish secure architecture, data governance, network segmentation and appropriate analytics.

18 Sensitivity and uncertainty analysis

18.1 PV-resource sensitivity

Table 4 gives the estimated daily PV yield for different peak-sun-hours, using the 14.4 kWp installed PV capacity and the same system factor of 0.78.

Table 4. Sensitivity of the estimated daily PV yield to peak-sun-hours (14.4 kWp, system factor 0.78).

Peak-sun-hours (h/day)	Estimated daily PV yield (kWh/day)
3.5	39.31
4.0	44.93
4.8	53.91
5.5	61.78

The results show that the planning estimate is sensitive to solar resource. The difference between 3.5 and 5.5 peak-sun-hours/day is approximately 22.47 kWh/day. Therefore, actual site irradiance and PV output monitoring should be implemented before final expansion sizing.

18.2 System-factor sensitivity

Table 5 gives the estimated daily PV yield for different system factors at 4.8 peak-sun-hours/day.

Table 5. Sensitivity of the estimated daily PV yield to the system factor (14.4 kWp, 4.8 peak-sun-hours/day).

System factor	Estimated daily PV yield (kWh/day)
0.70	48.38
0.78	53.91
0.85	58.75

18.3 Battery-availability sensitivity

For one 5 kWh battery at the administration load of 4.64 kW, theoretical autonomy varies with depth of discharge and battery-side efficiency. At 70% DoD and 90% efficiency, delivered energy is 3.15 kWh and autonomy is about 0.68 h. At 90% DoD and 97% efficiency, delivered energy is 4.37 kWh and autonomy is about 0.94 h. The central planning case of 80% DoD and 95% efficiency gives 0.82 h.

This confirms that uncertainty in battery operating assumptions is meaningful but does not change the main conclusion: one 5 kWh battery per 10 kVA inverter provides limited autonomy.

18.4 Uncertainty classification

The status and main uncertainty of each input variable are classified in Table 6.

Table 6. Uncertainty classification of the input variables.

Variable	Status	Main uncertainty
Transformer rating	Verified	None material for nameplate
PV module count/rating	Verified	Actual operating output

Variable	Status	Main uncertainty
Inverter rating	Verified	Actual PF/DC constraints
Battery quantity	Verified	Actual usable capacity and BMS limits
Battery nameplate	Verified	Field operating condition
Building loads	Supplied measured values	Measurement duration and PF
Peak-sun-hours	Assumption	Seasonal/weather variation
System factor	Assumption	Temperature, wiring, inverter and soiling losses
Campus maximum demand	Not captured	Missing full-campus survey
Annual energy consumption	Not captured	Missing time-series metering
Tariff/costs	Not supplied	Prevents economic optimization
Security incidents	Not documented	Requires institutional security records

19 Engineering implications

The first engineering implication is that battery expansion should be prioritized based on critical-load requirements rather than inverter nameplate capacity alone. The present 10 kVA inverter/5 kWh battery pairing provides a high inverter-to-storage ratio.

Second, the Electrical and Electronic Engineering Technology laboratories should be considered critical educational loads. Their combined connected load of 5.61 kW is modest relative to the 500 kVA transformer rating but significant relative to the institution's renewable-energy storage capacity.

Third, a dedicated laboratory critical-load feeder should be developed. The feeder should include appropriate overcurrent protection, surge protection, earthing, isolation, ATS/changeover functionality and energy metering.

Fourth, the laboratory load contains electrical machines and workshop equipment. Motor starting currents and transient behaviour must therefore be considered before selecting the final inverter rating. A 10 kVA inverter may pass a steady-state screening calculation because 5.61 kW is below its nameplate, but actual motor starting performance must be confirmed.

Fifth, future PV and battery expansion should be designed as a coordinated system. Adding PV without adequate storage may increase daytime generation without improving outage resilience. Adding storage without sufficient PV may provide backup but create a charging-energy deficit.

Sixth, all future infrastructure should be metered. Minimum instrumentation should include PV generation, battery voltage/current/SOC, inverter output, critical-load feeder energy, grid availability and generator operation.

Seventh, the institution should maintain a digital asset register containing equipment identification, location, rating, installation date, condition, maintenance history and calibration status.

20 Policy implications

The study supports six policy directions.

1. **Institutional Energy Policy:** Institutional energy policy should define critical loads. Administration, ICT, library, laboratories, security and emergency systems should not be treated identically during outages.
2. **Renewable-Energy Procurement Policy:** Renewable-energy projects should include storage, metering and energy-management requirements from the design stage.
3. **Laboratory Infrastructure Policy:** Laboratory infrastructure should be treated as a strategic educational asset. Reliable power for practical training should be included in institutional capital planning.
4. **Security Policy:** Security policy should integrate physical protection and cybersecurity. CCTV, access control and IoT devices should operate under an approved network and data-governance framework.
5. **Enrolment-Linked Infrastructure Planning:** Infrastructure expansion should be tied to enrolment forecasts and programme-accreditation requirements. The present low Electrical and Electronic Engineering Technology program enrolment should support staged expansion rather than indefinite postponement of practical infrastructure.
6. **Institutional Data Governance:** Future planning should rely on synchronized records for students, staff, energy, facilities, maintenance, and security.

21 Conclusion

This study established a verified engineering baseline for Federal Polytechnic Ngodo Isuochi and demonstrated that the institution's principal infrastructure challenge is one of integration and resilience rather than simple infrastructure absence.

The institution has five dedicated E/E practical facilities, substantial documented laboratory equipment, a 500 kVA transformer and a decentralised renewable-energy system comprising 14.4 kWp PV and 30 kVA of inverter capacity. Verification of the installed battery configuration is critical: only one 5 kWh, 51.2 V LiFePO₄ battery is installed per 10 kVA inverter. Consequently, total nominal battery storage is 15 kWh, not 90 kWh.

The corrected storage analysis shows that the present batteries provide only approximately 0.82–1.18 hours of theoretical autonomy at the measured loads of the administration, ICT and library buildings under the stated planning assumptions. The five E/E laboratories have a combined connected load of 5.61 kW and remain outside the installed solar supply boundary. This creates a direct resilience gap in the practical-training system.

The existing 14.4 kWp PV system is capable of producing approximately 53.91 kWh/day under the selected planning assumptions, but generation capacity alone does not guarantee laboratory continuity. A six-hour laboratory-support scenario requires approximately 8.99 kWp PV and 44.29 kWh nominal battery storage, equivalent to approximately nine 5 kWh batteries and thirty 300 W PV modules as a first-order planning reference. Final engineering design must consider load diversity, motor starting, irradiance, battery limits, inverter compatibility, protection and actual operating schedules.

The proposed Integrated Smart Technical Education and Infrastructure Resilience Framework connects physical infrastructure, energy resilience, laboratory readiness, ICT, intelligent security, maintenance, data analytics and governance. Its principal value is that it provides a staged engineering pathway that can grow with enrolment and institutional development.

The study therefore recommends a transition from isolated infrastructure projects to an integrated, metered and critically prioritized campus infrastructure strategy. Such an approach can improve educational continuity, support practical competency development, strengthen security, reduce dependence on temporary generation and improve the institution's long-term readiness for sustainable expansion and accreditation.

22 Future research

Future work should establish a 12-month interval energy-monitoring dataset covering grid availability, PV generation, inverter output, battery SOC, critical-load consumption and generator operation. The next phase should also conduct:

- laboratory-by-laboratory load profiling
- motor-starting and transient analysis
- power-factor measurement
- battery degradation assessment
- solar-resource measurement
- full-campus maximum-demand determination
- techno-economic optimization
- carbon-emission assessment
- reliability and resilience indices
- security risk scoring
- IoT cybersecurity assessment
- AI-based anomaly detection
- digital-twin development
- experimental validation of the proposed laboratory microgrid

The future optimization study should use measured time-series data and compare centralized, decentralized and networked campus-energy architectures.

Data availability

The study is based on institutional information, an institutional physical-facilities/equipment inventory, installed-system nameplate information and supplied connected-load measurements. The underlying institutional records are not publicly deposited because they may contain internal operational information. Non-sensitive derived datasets and model parameters can be made available by the corresponding author upon reasonable request and subject to institutional authorization.

Ethics statement

This study did not involve human-subject experimentation, clinical data or intervention. No personally identifiable student or staff information was analyzed. The study used institutional

infrastructure, equipment, energy and aggregate enrolment information for engineering planning. Institutional authorization should be obtained before public release of sensitive facility layouts, security-system details or operational records.

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