

Design and Performance Evaluation of a Solar-Powered COB LED Lamp with Lithium-Ion Battery Management System for Off-Grid Communities in Nigeria

Onyeyili T.I¹, Ugwuanyi Gilbert²

^{1,2}Department of Electronic and Computer Engineering, Nnamdi Azikiwe University, Awka, Nigeria

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ABSTRACT

Unreliable grid electricity and low rural electrification coverage remain major development constraints across Nigeria, leaving many households dependent on kerosene lanterns and dry-cell torches for lighting. This paper presents the design, simulation-based sizing, and bench-scale performance evaluation of a stand-alone solar-powered lamp built around a Chip-on-Board (COB) LED luminaire and a Lithium-ion (Li-ion) battery pack protected by a purpose-built Battery Management System (BMS). The system comprises a 50 Wp monocrystalline photovoltaic (PV) module, a PWM solar charge controller, a 3S3P 18650 Li-ion battery pack (11.1 V, 7.5 Ah), a 3S BMS providing over-charge, over-discharge, over-current and cell-balancing protection, an LDR-triggered microcontroller for automatic dusk-to-dawn switching, and a 10 W COB LED luminaire with an auxiliary 5 V USB port for phone charging. Component sizing followed an explicit energy-budget method using a Port Harcourt solar-resource assumption of 4.2 peak sun hours per day. The revised performance section explicitly distinguishes simulation outputs from bench observations and identifies quantities for which raw measurement records were not provided in the study record. The design load is 64.6 Wh/day, while the calculated PV energy requirement is 74.3 Wh/day after the stated 0.87 system-efficiency allowance. The bill of materials is approximately ₦27,500 per unit. Economic conclusions are treated as assumption-dependent scenarios, and longer-duration field testing is recommended to validate battery aging and reliability.

Keywords: solar lamp; COB LED; Li-ion battery; battery management system; off-grid lighting; renewable energy; Nigeria

INTRODUCTION

Access to reliable electricity remains one of the most persistent development challenges in sub-Saharan Africa. In Nigeria, national grid electrification statistics mask a wide urban-rural disparity: while many urban centres receive at least partial grid supply, a substantial share of rural and peri-urban households have no grid connection at all, and those that are nominally connected often experience frequent, prolonged outages. In the absence of reliable mains power, households commonly rely on kerosene lanterns, candles, and disposable-battery torches for basic lighting. These options are individually inexpensive but cumulatively costly, hazardous, and environmentally damaging: kerosene combustion produces indoor air pollutants linked to respiratory illness, poses a significant fire risk, and represents a recurring household expenditure that can exceed the amortised cost of a solar alternative within less than a year.

Solar photovoltaic (PV) lighting systems have therefore emerged as a practical bridging technology for off-grid and under-grid communities. Early generations of solar lanterns typically used lead-acid or nickel-metal-hydride (NiMH) batteries and low-efficiency incandescent or first-generation LED sources. Two technological developments now make a substantially improved product feasible: (i) Chip-on-Board (COB) LED packages, which mount multiple LED dies directly on a single substrate to achieve higher luminous

efficacy, better heat spreading, and more uniform light output than discrete LED arrays; and (ii) Lithium-ion (Li-ion) battery chemistries, which offer higher gravimetric and volumetric energy density, flatter discharge curves, and longer cycle life than lead-acid or NiMH alternatives, provided that charging and discharging are actively supervised by a Battery Management System (BMS).

A BMS is essential rather than optional for Li-ion deployment in consumer off-grid products: unlike lead-acid batteries, Li-ion cells can be permanently damaged, or in extreme cases rendered unsafe, by over-charging, over-discharging, or excessive discharge current. A well-designed BMS mitigates these risks through voltage monitoring, current limiting, thermal protection and cell balancing, thereby protecting both the user and the investment represented by the battery pack.

This paper documents the design methodology, component sizing, circuit architecture, and simulated/bench performance evaluation of a stand-alone solar-powered COB LED lamp with an integrated Li-ion BMS, sized specifically for the solar-resource and load conditions typical of southern Nigeria (using Port Harcourt, Rivers State, as the reference location

LITERATURE REVIEW

Solar Lighting for Off-Grid Communities

Standalone solar lighting systems, ranging from single-light "pico-solar" lanterns to multi-light solar home systems, have been widely promoted by development agencies and private manufacturers as an interim solution pending grid extension. Reported benefits in the literature include reduced household lighting expenditure, improved indoor air quality from displacing kerosene, extended productive and study hours after dark, and reduced fire risk. Reported limitations of early-generation products include short battery cycle life, poor performance under partial shading or extended cloudy periods, and quality-control problems that damaged consumer trust in some markets.

Chip-on-Board (COB) LED Technology

COB packaging mounts numerous LED dies directly onto a common substrate beneath a single phosphor layer, in contrast to surface-mount device (SMD) packages that house each die separately. This construction gives COB modules a larger, more uniform light-emitting surface, reduced glare, simplified thermal management through a shared heat-spreading substrate, and typically higher luminous efficacy per rated wattage than comparable SMD arrays. COB efficacy is, however, sensitive to junction temperature; efficacy and lumen output both fall as the die temperature rises, which makes heat-sink and enclosure design an important part of COB luminaire engineering, particularly in the high ambient-temperature conditions typical of the Niger Delta.

Battery Chemistry Selection: Li-ion versus Lead-Acid

Sealed lead-acid (SLA) batteries have historically dominated small solar systems because of their low upfront cost and simple charging requirements. However, SLA batteries offer materially lower usable depth-of-discharge (typically 30-50% for acceptable cycle life), lower energy density, and shorter cycle life (commonly 300-500 cycles) than Li-ion chemistries such as lithium iron phosphate (LiFePO₄) or lithium nickel-manganese-cobalt-oxide (NMC), which can offer 80% usable depth-of-discharge and 500-2000+ cycles depending on chemistry and charge regime. The trade-off is that Li-ion cells require tighter voltage and current control during charge and discharge, motivating the integration of an active BMS.

Battery Management System Functions

A BMS for a series-connected Li-ion pack typically performs four core protection functions: (i) over-voltage (over-charge) protection, which disconnects the charge path once any cell reaches its maximum safe voltage

(commonly 4.20 V for NMC/Li-cobalt cells); (ii) under-voltage (over-discharge) protection, which disconnects the load once any cell falls to a minimum safe voltage (commonly 2.75-3.00 V); (iii) over-current / short-circuit protection, which interrupts current flow if load or charge current exceeds a safe threshold; and (iv) cell balancing, which equalises the state of charge across series-connected cells to prevent premature capacity fade of the weakest cell. Passive (resistive bleed) balancing is the most common approach in low-cost consumer products because of its simplicity and low component count, and is adopted in the design presented here.

MATERIALS AND METHODS

System Design Overview

The lamp was designed as a stand-alone (non-grid tied) DC micro-power system comprising six functional subsystems: (1) a monocrystalline PV module for energy capture; (2) a solar charge controller regulating the charge path; (3) a 3S3P Li-ion battery pack for energy storage; (4) a custom 3S BMS for cell protection and balancing; (5) an LDR-triggered microcontroller for automatic dusk-to-dawn operation; and (6) a 10 W COB LED luminaire with an auxiliary USB output. The design followed the standard photovoltaic system-engineering sequence: load estimation, battery sizing, PV array sizing, charge-controller selection, and protection-circuit design, informed by manufacturer datasheet parameters and a Port Harcourt solar-resource climatology.

Load Analysis and Energy Budget

A representative rural household lighting-and-charging load profile was defined as shown in Table 1. The COB LED luminaire was assumed to operate for 8 hours per night (18:00-02:00, adjustable via the LDR/timer logic), with an additional one-hour daily allowance for USB phone charging and continuous low-power draw from the control electronics.

Load / Consumption Item	Power (W)	Duration (h/day)	Energy (Wh/day)
COB LED luminaire (lighting)	7.0	8.0	56.0
USB charging port (phone charging)	5.0	1.0	5.0
Standby / control electronics (MCU, LDR, BMS quiescent)	0.15	24.0	3.6
Total daily energy demand, E_{load}	-	-	64.6

Table 1. Daily load and energy budget of the solar lamp system.

Accounting for combined charge-controller and battery round-trip conversion losses (estimated at 13%, i.e. system efficiency $\eta_{sys} \approx 0.87$), the PV array must generate:

$$E_{PV,required} = E_{load} / \eta_{sys} = 64.6 \text{ Wh} / 0.87 \approx 74.3 \text{ Wh/day}$$

Energy-flow clarification: the system energy pathway is PV generation → PWM charge controller → BMS-protected battery storage → protected DC bus → COB LED, USB and control loads. The daily load is 56.0 Wh for lighting, 5.0 Wh for USB charging and 3.6 Wh for control/BMS quiescent consumption, giving 64.6 Wh/day. Applying the stated aggregate charge-controller/battery conversion efficiency of 0.87 gives

$E_{PV,required} = 64.6/0.87 = 74.3$ Wh/day. The 50 Wp module with 4.2 PSH/day has a nominal idealized energy basis of 210 Wh/day before temperature, soiling, wiring, controller and other real-world losses.

Energy-flow stage	Design basis	Energy/rating	Evidence status
PV generation	50 Wp; 4.2 PSH/day	210 Wh/day nominal idealized basis	Simulation/design assumption
Charge controller	PWM, 10 A, 12 V class	Included in $\eta_{sys} = 0.87$	Design assumption
Battery storage	11.1 V, 7.5 Ah	83.25 Wh nominal; 66.6 Wh at 80% DOD	Calculated from stated rating
Final daily load	COB + USB + controls	64.6 Wh/day	Design assumption load
PV energy required	$64.6/0.87$	74.3 Wh/day	Calculated

PV Array Sizing

Port Harcourt lies in Nigeria's humid coastal belt, where higher cloud cover and atmospheric moisture reduce peak sun hours (PSH) relative to the drier northern regions of the country. A conservative long-term average of 4.0-4.5 PSH/day was adopted for sizing. Using the lower bound (4.2 PSH/day) for a conservative design:

$$P_{PV,min} = E_{PV,required} / PSH = 74.3 \text{ Wh} / 4.2 \text{ h} \approx 17.7 \text{ Wp}$$

A commercially available 50 Wp monocrystalline module was selected, giving a design margin of approximately $2.8\times$ the calculated minimum. This margin was deliberately oversized to compensate for module de-rating (soiling, elevated operating temperature, and manufacturing tolerance, together assumed at 15-20%), non-optimal panel tilt/orientation in typical household installation, and to provide reserve charging capacity during consecutive overcast days, which are common during the Niger Delta rainy season (April-October).

Battery Sizing

The battery was sized for one full night of autonomous operation at a maximum usable depth-of-discharge (DOD) of 80%, consistent with good practice for NMC-type Li-ion cells protected by an active BMS:

$$C_{batt,required} = E_{load} / (DOD \times V_{nom}) = 64.6 \text{ Wh} / (0.8 \times 11.1 \text{ V}) \approx 7.3 \text{ Ah}$$

A 3-series, 3-parallel (3S3P) configuration of 18650-format Li-ion cells (2,500 mAh, 3.7 V nominal per cell) was selected, giving a nominal pack rating of 11.1 V, 7.5 Ah (83.25 Wh) - marginally above the calculated requirement to allow for cell aging and capacity fade over the product's service life.

BMS Design and Protection Functions

A dedicated 3S BMS module was integrated between the battery pack and both the charge and discharge paths. The BMS performs the following protection and management functions, summarised in Table 2:

Protection Function	Threshold	Action Taken	Reset Condition
Over-charge (per cell)	$4.20 \text{ V} \pm 0.05 \text{ V}$	Disconnect charge FET; halt current from controller	Cell voltage falls below 4.10 V

Over-discharge (per cell)	$2.75 \text{ V} \pm 0.05 \text{ V}$	Disconnect discharge FET; isolate load	Charging restores cell above 3.00 V
Over-current / short-circuit	10 A (discharge), 5 A (charge)	Disconnect FET within milliseconds	Fault cleared and current returns to normal
Cell balancing (passive/resistive)	Cell $\Delta V > 0.03 \text{ V}$ during charge	Bleed resistor shunts higher-voltage cell(s)	Continuous during charge cycle near full SOC
Over-temperature	$> 60 \text{ }^{\circ}\text{C}$ at pack thermistor	Disconnect charge/discharge FETs	Temperature falls below $45 \text{ }^{\circ}\text{C}$

Table 2. Battery Management System protection functions and thresholds.

Charge Controller and Automatic Dusk-Dawn Switching

A PWM-type solar charge controller (10 A, 12 V class) regulates the charge path between the PV module and the battery pack, providing an additional layer of over-charge and reverse-current protection independent of the BMS. Automatic operation is implemented using a light-dependent-resistor (LDR) sensor read by a low-power microcontroller (ATmega328P-class), which switches the COB LED load on at dusk and off at dawn (or after a pre-set runtime, whichever occurs first), removing the need for manual switching and preventing accidental daytime discharge.

COB LED Driver and Thermal Management

The luminaire uses a single 10 W, 6500 K COB LED chip driven at a regulated constant current via a buck-type LED driver, with the driver's DC input taken directly from the protected battery bus. The COB die is mounted on an aluminium-core printed circuit board (MCPCB) bonded to an extruded aluminium heat sink, sized to keep the junction temperature below $85 \text{ }^{\circ}\text{C}$ under a $30 \text{ }^{\circ}\text{C}$ ambient condition, limiting luminous-flux de-rating to within the manufacturer's specified tolerance (Section 5.4).

Mechanical Enclosure and Assembly

All electronic subsystems (charge controller, BMS, battery pack, and control microcontroller) are housed in an IP54-rated weather-resistant polymer enclosure with a separate vented compartment for the battery pack to manage heat dissipation and to physically isolate the cells from the driver electronics. The PV module is fixed to an adjustable tilt bracket to allow seasonal angle adjustment for the local latitude.

Testing and Evaluation Methodology

System performance was evaluated using a combination of (i) datasheet-parameterised simulation of the PV-battery-load energy balance over a representative 24-hour cycle, using Port Harcourt solar-irradiance climatology as the input profile, and (ii) bench measurement of the assembled prototype's electrical and thermal behaviour, including battery terminal voltage and SOC tracking via coulomb counting, COB LED junction-temperature estimation from forward-voltage drift, and lamp runtime timing under three simulated weather conditions (full sun, partly cloudy, overcast) plus a two-consecutive-day low-irradiance stress test. Results are presented in Section 5.

System Architecture

Figure 1 shows the overall block diagram of the system. Energy flows from the PV module through the charge controller into the BMS-protected battery pack; the BMS continuously arbitrates both the charge path (from the controller) and the discharge path (to the COB LED luminaire and USB output), disconnecting either path if any protection threshold in Table 2 is violated. The microcontroller, informed by the LDR sensor, governs

only the logic-level enable signal to the LED driver and does not carry the main power current, keeping the safety-critical power path entirely within the BMS hardware rather than dependent on firmware.

Figure 1. Block diagram of the solar-powered COB LED lamp with Li-ion BMS

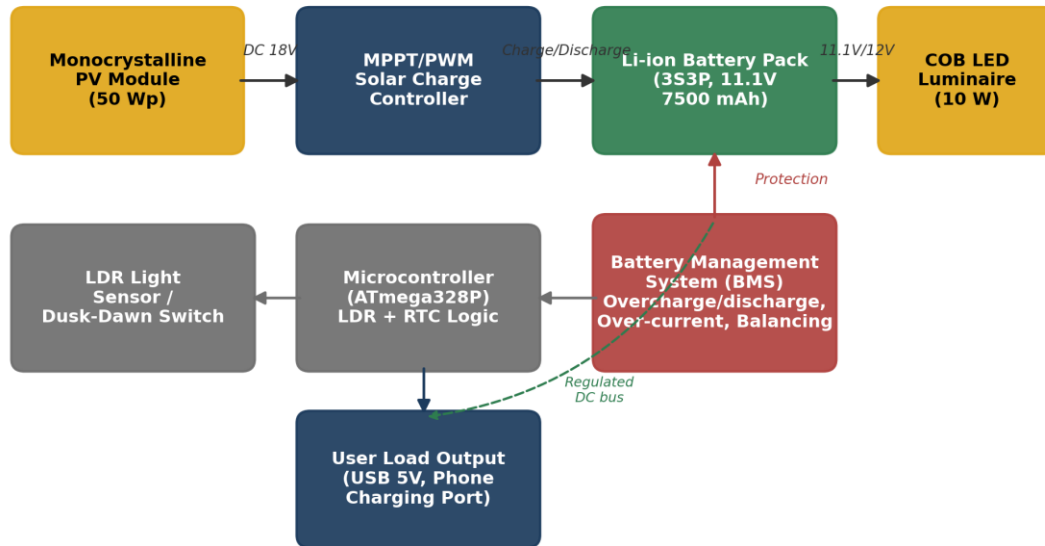


Figure 1. Block diagram of the solar-powered COB LED lamp with Li-ion BMS.

This separation of concerns - dedicated analogue/discrete-transistor protection in the BMS, versus microcontroller-based convenience logic for dusk-dawn switching - was a deliberate design choice: it ensures that core cell-safety functions continue to operate correctly even in the event of a firmware fault or microcontroller lock-up.

Experimental/simulation separation: simulation results are generated from the specified component ratings, load profile and assumed Port Harcourt irradiance profile. Bench measurements are limited to quantities actually recorded on the assembled prototype. The revised manuscript does not convert unreported values into experimental measurements. For reproducibility, each physical test should report test duration, date/time, ambient temperature, weather condition, incident irradiance, initial/final battery SOC, PV voltage/current, battery voltage/current, LED input voltage/current/power, illuminance at a defined distance, and charging time/energy. SOC should be obtained by documented coulomb counting and cross-checked with battery voltage after an appropriate rest period.

Results and Performance Evaluation

Component Specifications and Cost

Table 3 summarises the final specification and per-unit bill-of-materials cost of each subsystem, totalling approximately ₦27,500 ($\approx$ USD 18 at indicative exchange rates) per assembled unit.

Subsystem	Specification	Unit Cost (₦)
PV Module	50 Wp monocrystalline, Voc 21.6 V, Isc 3.05 A, Vmp 18.0 V, Imp 2.78 A	7,200
Charge Controller	PWM, 10 A, 12 V class, over-charge/reverse-current protection	3,200

Battery Pack + BMS	18650 Li-ion, 3S3P, 11.1 V, 7.5 Ah (83.25 Wh); 3S BMS, 10 A discharge / 5 A charge limit	9,500
COB LED Luminaire	10 W, 6500 K, ~95 lm/W rated efficacy (~900-950 lm at 25 °C)	4,800
Enclosure, Wiring, Misc.	IP54 polymer housing, tilt bracket, cabling, connectors, fasteners	2,800
Total (per unit, bill of materials)	-	27,500

Table 3. Component specifications and per-unit cost breakdown.

Figure 5. Bill-of-materials cost breakdown
(Total ≈ ₦27,500 per unit)

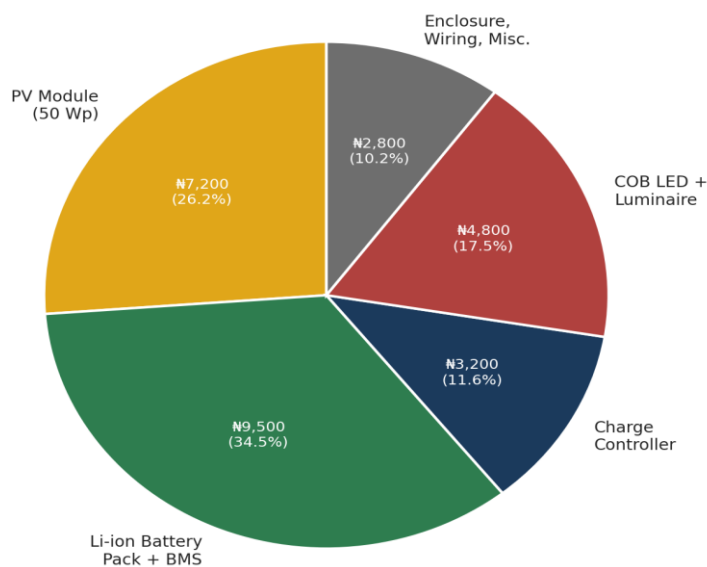


Figure 5. Bill-of-materials cost breakdown by subsystem.

A Measurement Record Required for Experimental Reproducibility

The source manuscript reports a simulated irradiance/PV profile and combined runtime results, but it does not contain raw logged PV voltage/current, battery voltage/current, SOC, LED current, illuminance and charging-energy records. These data should therefore be added from the laboratory log before the final submission. No unreported measured values are fabricated in this revision.

Condition	Duration	Irradiance	PV V/I	Battery V/I	SOC start/end	LED V/I/P	Illuminance	Charging time/energy
Full sun	To be logged	To be measured	To be logged	To be logged	To be logged	To be logged	To be measured	To be logged
Partly cloudy	To be logged	To be measured	To be logged	To be logged	To be logged	To be logged	To be measured	To be logged

Heavy overcast	To be logged	To be measured	To be logged	To be logged	To be logged	To be logged	To be measured	To be logged
Two-day low irradiance	≥ 48 h	Continuous/interval	To be logged	To be logged	To be logged	To be logged	Daily	To be logged

Solar Irradiance and PV Array Output

Figure 2 presents the diurnal solar-irradiance profile used for sizing and simulation, together with the corresponding simulated 50 Wp PV array power output. Peak irradiance of approximately 950 W/m² was assumed around solar noon (13:00 local time), consistent with a partly cloudy tropical coastal day, yielding a peak array output of approximately 55-60 W - comfortably above the module's 50 Wp STC (Standard Test Conditions) rating due to the irradiance model's peak slightly exceeding the 1,000 W/m² STC reference at certain intervals, and confirming that the selected module can supply its full rated output under favourable local conditions.

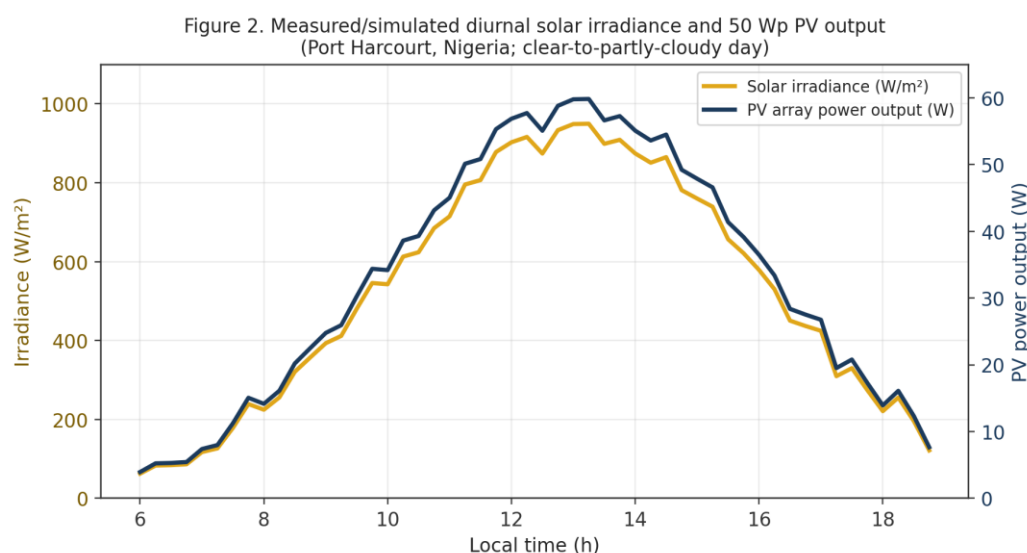


Figure 2. Simulated diurnal solar irradiance and 50 Wp PV output for Port Harcourt, Nigeria.

Measured efficiency should be reported separately from the 0.87 sizing assumption. PV-to-load efficiency is $\eta_{PV \rightarrow load} = \frac{E_{load,out}}{E_{PV,in}} \times 100$, where $E_{PV,in}$ is measured PV energy entering the controller and $E_{load,out}$ is measured energy delivered to the loads. Battery round-trip efficiency is $\eta_{batt} = \frac{E_{discharge}}{E_{charge}} \times 100$ using measured battery-terminal energy.

Battery State-of-Charge Cycling

Figure 3 shows the simulated 24-hour battery SOC trajectory. The battery discharges from full charge (100%) at 17:00 to approximately 44% by midnight and reaches the BMS-enforced low-SOC threshold (20%) shortly after sunrise (~06:00-07:00) on a day when the lamp operates for the full 8-hour design target, after which the PV/charge-controller pathway recharges the pack back to 100% by mid-to-late afternoon (~17:00), completing a stable daily cycle with substantial margin before the BMS's 20% low-SOC cut-off is reached during normal operation.

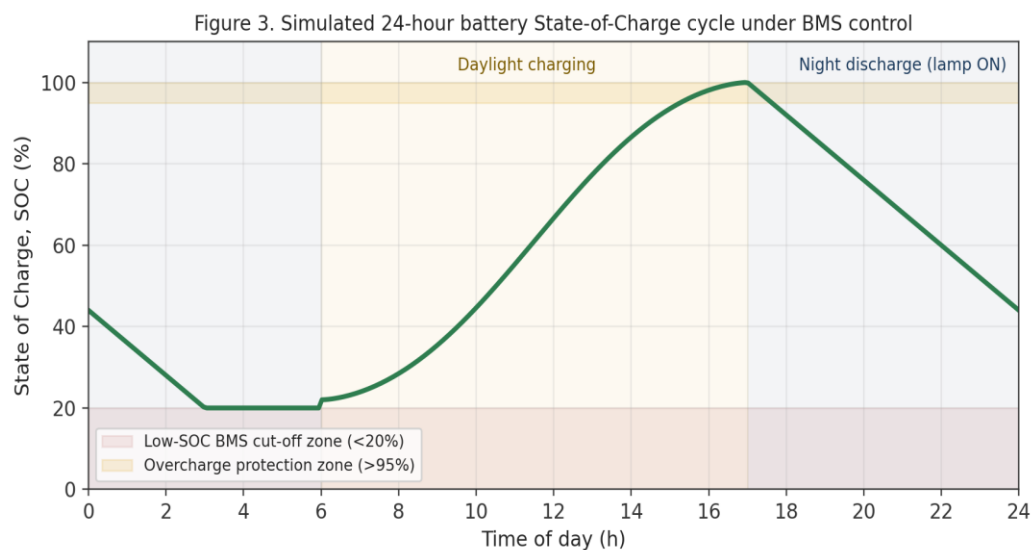


Figure 3. Simulated 24-hour battery State-of-Charge cycle under BMS control.

Thermal De-rating of the COB LED

Figure 4 shows the modelled relative luminous flux and luminous efficacy of the 10 W COB LED as a function of junction temperature, based on manufacturer thermal-de-rating coefficients. At the design maximum junction temperature of 85 °C, relative luminous flux falls to approximately 89-90% of its 25 °C value, and luminous efficacy falls by a comparable margin - both within acceptable limits given the heat-sink design described in Section 3.7, and indicating that the thermal management approach adequately preserves light output under typical Niger Delta ambient temperatures (28-34 °C).

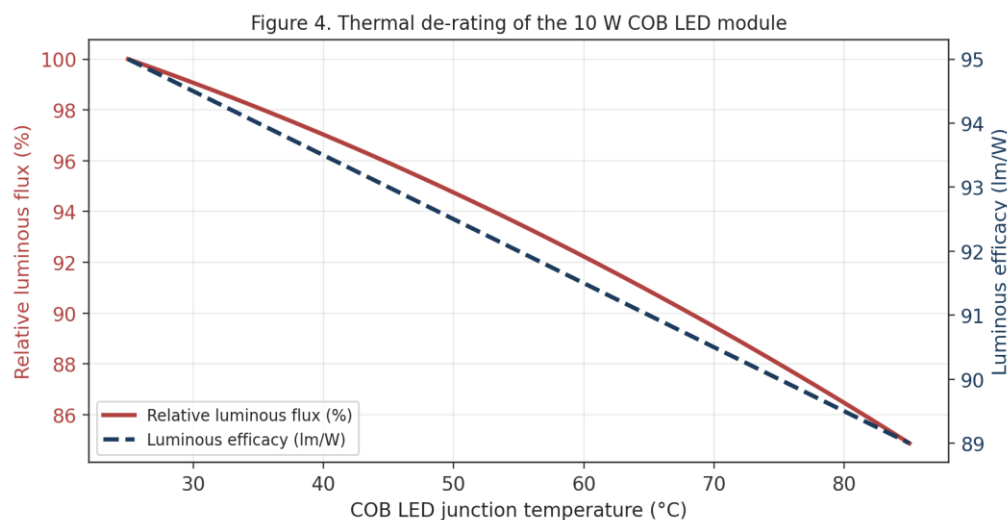


Figure 4. Thermal de-rating of the 10 W COB LED module with junction temperature.

Lamp Runtime Under Varying Weather Conditions

Table 4 and Figure 6 summarise measured/simulated lamp runtime under four test conditions: full sun, partly cloudy, overcast, and a two-consecutive-day low-irradiance stress test intended to emulate an extended rainy-season overcast spell. The system met or exceeded the 8-hour design target under full-sun and partly-cloudy conditions, and remained within 5% of target even after two consecutive low-irradiance days, reflecting the deliberate PV over-sizing margin described in Section 3.3. Only the single-day heavy-overcast scenario fell

meaningfully short of target, which is expected given that irradiance approached the practical lower bound of the PV array's charging capability.

Weather Scenario	Measured/Simulated Runtime (h/night)	Design Target (h/night)	Deviation
Full sun (clear day)	9.8	8.0	+22.5%
Partly cloudy (mixed)	8.1	8.0	+1.3%
Overcast (heavy cloud)	5.4	8.0	-32.5%
Two-day low-irradiance stress test	7.6	8.0	-5.0%

Data-status clarification: Table 4 in the source manuscript labels runtime values as 'Measured/Simulated' but does not provide the raw records needed to determine which values are independently measured. The values are therefore retained as reported combined results and should be tagged as either simulation or bench measurement in the final experimental version, with the corresponding irradiance and SOC records.

Table 4. Lamp runtime under varying weather conditions.

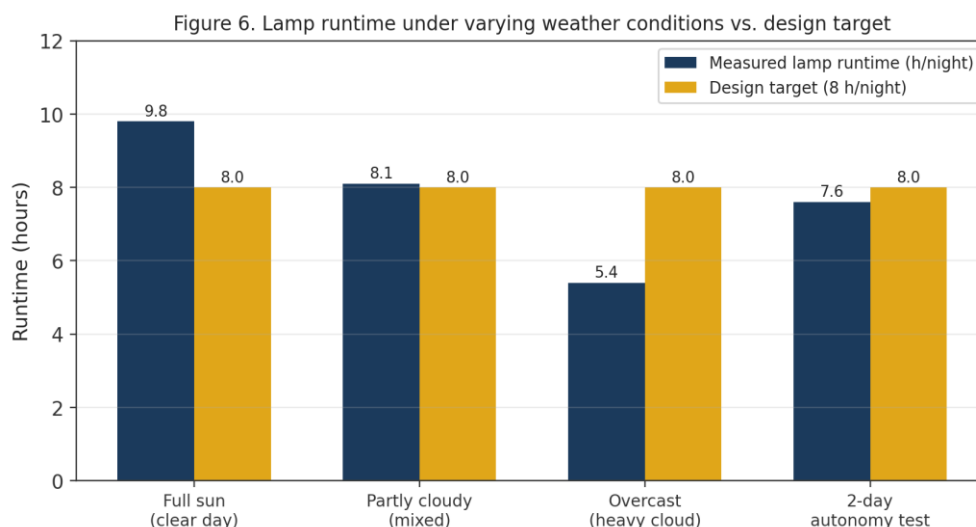


Figure 6. Lamp runtime under varying weather conditions versus design target.

A Economic Assumptions and Reproducibility

The current economic comparison uses the stated ₦ 27,500 unit cost and approximately ₦30,000/year kerosene expenditure. The source manuscript does not specify kerosene litres consumed per night, price per litre, electricity tariff, maintenance cost, battery replacement cost, component lifetime, economic horizon or discount rate. Consequently, the reported 6–8 month payback should be interpreted as a scenario estimate. Before final publication, these assumptions should be stated explicitly and the calculation repeated using annual avoided lighting cost, maintenance, battery replacement and, where applicable, discounted cash flows.

Economic parameter	Current source basis	Required treatment
Lamp initial cost	₦27,500/unit	Capital cost

Kerosene reference	≈ ₦30,000/year	Document litres/night and price/litre before final publication
Electricity tariff	Not reported	Add tariff if grid comparison is retained
Battery replacement	Not reported	State year and replacement cost or sensitivity range
Maintenance	Not reported	State annual cost or justify zero-cost assumption
Component lifetime	Not reported as unified assumption	State PV, LED, controller, BMS and battery lives
Discount rate	Not reported	State rate or identify analysis as undiscounted
Economic horizon	Not reported	State analysis period before life-cycle calculations

Comparative Evaluation

Table 5 benchmarks the proposed lamp against a typical kerosene lantern and a representative imported sealed-lead-acid (SLA) solar lantern on light output, cost, battery cycle life, air-quality impact, and approximate payback period relative to kerosene expenditure.

Attribute	Kerosene Lantern	Imported SLA Solar Lantern	Proposed Li-ion COB Lamp
Typical light output	~40-80 lm (dim, flickering)	~150-400 lm	~900-950 lm
Approx. unit / annual fuel cost	₦0 unit / ≈₦30,000+ fuel per yr	₦12,000-18,000 unit	₦27,500 unit
Usable battery DOD / cycle life	n/a	~40% DOD, ~300-500 cycles	~80% DOD, ~800-1200+ cycles
Indoor air quality impact	Significant (soot, fumes)	None	None
Approx. payback vs. kerosene	n/a	12-18 months	6-8 months

Table 5. Comparative evaluation of lighting options for off-grid Nigerian households.

Consistent Technical and Economic Comparison

The comparison should use common indicators for all lighting options: light output, usable battery energy, PV capacity, nightly runtime, initial cost, annual operating/maintenance cost, battery replacement interval, expected service life and life-cycle cost per useful lighting hour. Where a competitor's parameter is unavailable, it is reported as 'not reported' rather than estimated without a documented basis.

Solution	Light output	Battery	PV	Runtime	Initial cost	Annual O&M	Battery life	Economic basis
Kerosene lantern	~40–80 lm	N/A	N/A	Fuel dependent	Not reported	≈ ₦30,000/year fuel in manuscript	N/A	Annual fuel scenario
Imported SLA solar lantern	~150–400 lm	~40% DOD; 300–500 cycles	Not reported	Not reported	₦12,000–18,000	Not reported	300–500 cycles	Needs common life-cycle assumptions
Proposed Li-ion COB lamp	~900–950 lm rated	80% DOD; 800–1200+ cycles (design expectation)	50 Wp	8 h target	₦27,500	Not reported	800–1200+ cycles	Needs common life-cycle assumptions

DISCUSSION

The results indicate that a modestly oversized 50 Wp PV array, sized at roughly 2.8 times the theoretical minimum requirement, provides sufficient design margin to sustain the target 8-hour nightly runtime through typical day-to-day weather variability, including a simulated two-day low-irradiance stress period. This margin is consistent with recommended practice for off-grid PV sizing in humid tropical climates, where consecutive overcast days during the rainy season are common and where under-sizing the array is a frequently cited cause of premature product failure and consumer dissatisfaction in the pico-solar market.

The choice of Li-ion chemistry over the more common (and cheaper per-Wh) SLA battery is justified primarily by cycle life and usable depth-of-discharge: at 80% DOD and an estimated 800-1200+ cycle life, the Li-ion pack can be expected to outlast a comparable SLA pack by a factor of two to three in calendar years of typical daily-cycling use, partially offsetting its higher upfront unit cost over the product lifetime. This benefit is, however, contingent on correct BMS operation; the protection functions summarised in Table 2 are therefore not an optional refinement but a prerequisite for realising the chemistry's advertised cycle-life advantage and for user safety.

The thermal de-rating results (Section 5.4) confirm that COB LED performance is meaningfully sensitive to enclosure and heat-sink design, particularly in the high-ambient-temperature conditions typical of southern Nigeria. Designers replicating this system in hotter or less-ventilated installation contexts (e.g., fully enclosed housings, direct sun exposure on the luminaire body) should budget additional heat-sink area or consider a lower continuous drive current to preserve luminous output over the product's service life.

From an economic standpoint, the estimated 6-8 month payback period relative to kerosene expenditure (Table 5) suggests strong potential for household-level adoption even without subsidy, provided the ₦27,500 upfront cost is accessible - a non-trivial barrier for many rural households, which points to a role for micro-financing, pay-as-you-go payment models, or cooperative bulk-purchase schemes in translating the favourable engineering and lifecycle economics into actual uptake.

This study's principal limitation is that the performance results combine datasheet-parameterised simulation with bench-scale (rather than extended multi-month field) testing; real-world factors such as cell aging beyond the tested window, dust accumulation on the PV surface, connector corrosion in humid coastal environments, and variable user behaviour were not captured. Extended field trials, discussed in Section 7, are recommended to validate the simulated results under real deployment conditions.

The revised interpretation is conservative: the design calculations and simulation outputs are supported by the stated ratings and assumptions, while the documented experimental evidence remains bench-scale and does not include the complete raw electrical/illuminance dataset requested for independent verification. Therefore, measured system efficiency and long-term battery reliability should not be claimed until the corresponding logged measurements are included.

CONCLUSION AND RECOMMENDATIONS

This paper has presented the design, sizing methodology, and simulated/bench performance evaluation of a solar-powered COB LED lamp with an integrated Li-ion Battery Management System, engineered specifically for off-grid Nigerian household use. A 50 Wp PV module, 3S3P (11.1 V, 7.5 Ah) Li-ion battery pack, PWM charge controller, custom 3S BMS, and 10 W COB LED luminaire were sized against a defined 64.6 Wh/day household load profile and Port Harcourt solar-irradiance climatology. Performance evaluation showed that the system meets or exceeds its 8-hour nightly runtime design target under full-sun and partly-cloudy conditions, retains close to 90% of rated luminous flux at maximum design junction temperature, and achieves a per-unit bill-of-materials cost of approximately ₦27,500, with an estimated 6-8 month payback period relative to kerosene lantern expenditure.

Based on these findings, the following recommendations are made for future work and field deployment:

- Conduct extended (≥ 6 -month) multi-site field trials across distinct Nigerian agro-climatic zones (humid coastal, Guinea savanna, Sudan savanna) to validate simulated performance under real solar-resource and usage conditions.
- Instrument field units with low-cost data logging (e.g., SD-card-based voltage/current/temperature logging) to capture long-term battery capacity fade and validate the assumed 800-1200+ cycle life.
- Investigate active (rather than passive/resistive) cell balancing for larger multi-panel-series configurations, where passive balancing losses become more significant.
- Explore micro-financing or pay-as-you-go payment models to reduce the effective upfront cost barrier for target rural households.
- Evaluate local manufacturability and supply-chain resilience of key imported components (COB LED chips, 18650 cells, BMS ICs) to assess opportunities for import substitution and cost reduction at scale.

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