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Techno-Economic Life-Cycle Cost Assessment of Lithium Iron Phosphate and Tubular Lead-Acid Batteries for Small Enterprise Solar Backup Systems in Nigeria

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Abstract: *Small enterprises across Nigeria rely on solar-charged battery backup to withstand frequent grid outages, yet the storage market now offers two competing chemistries at very different prices: the familiar tubular lead-acid battery and the newer, roughly twice-priced lithium iron phosphate pack. This study resolves the purchasing decision with a transparent ten-year life-cycle cost model applied under outage regimes of four, eight and twelve hours per day. Each bank is sized to its chemistry-appropriate depth of discharge; service life is taken as the lesser of cycle life and a thermally derated calendar life at a thirty-degree-Celsius operating ambient; and capital, replacement, maintenance and round-trip loss energy are discounted to net present cost and levelised cost of storage. Model parameters are drawn from manufacturer data, a July 2026 Nigerian distributor price survey and published ageing models rather than field measurements. Lithium iron phosphate returns the lower net present cost in every regime, about thirty-one percent below lead-acid, with a levelised cost of 0.199 against 0.286 United States dollars per kilowatt hour. The decisive mechanism is tropical heat, which cuts effective lead-acid calendar life to about 3.5 years and forces two replacements within the horizon. The advantage survives one-at-a-time sensitivity and a ten-thousand-draw Monte Carlo analysis, persisting in 97.3 percent of cases, and holds until the installed lithium price exceeds about 435 dollars per kilowatt hour. Further studies should validate these results against field measurements of bank temperature, cycling depth and realised failure ages in Nigerian installations.*

Keywords: *Battery Storage, Life-Cycle Cost, Lithium Iron Phosphate, Lead-Acid, Solar Backup, Nigeria*

Nomenclature	
BMS	Battery Management System
DoD	Depth of Discharge
LCOS	Levelised Cost of Storage
LFP	Lithium Iron Phosphate
NPC	Net Present Cost

INTRODUCTION

Unreliable grid electricity is among the most heavily documented constraints on Nigerian enterprise. Generation capacity persistently falls short of demand, and firms respond by self-supplying through generators and, increasingly, through solar backup systems built around a battery bank (Adeyeye & Mbohwa, 2025). Successive rounds of the World Bank Enterprise Surveys have found Nigerian firms reporting some of the most frequent power outages recorded anywhere, with the associated losses cited by a majority of firms as a major business obstacle (World Bank, 2014). Falling photovoltaic prices and the strong solar resource of the north have made the solar-charged battery system the default resilience investment for shops, offices, pharmacies, cold stores and similar small enterprises (Ohunakin *et al.*, 2014; World Health Organization, 2014). Within that investment, the battery bank is both the largest cost element and the shortest-lived component, and the market now presents buyers with a genuine choice. Tubular lead-acid batteries dominate Nigerian retail: they are locally familiar, widely serviced and cheap per labelled kilowatt hour. Lithium iron phosphate packs have entered the market at up to roughly twice the installed price but promise several times the cycle life, deeper usable discharge and higher round-trip efficiency (Zubi *et al.*, 2018; May *et al.*, 2018). International cost analyses consistently favour lithium chemistries for daily-cycled stationary storage (Julch, 2016; Schmidt *et al.*, 2019; IRENA, 2017), but those studies assume temperate operating conditions and mature supply chains.

Two Nigerian particulars change the arithmetic in ways that have not been quantified in the local literature: batteries here cycle nearly every day because outages occur nearly every day, and they do so at ambient temperatures that materially accelerate lead-acid ageing (Coccato *et al.*, 2025; Kuznetsov *et al.*, 2026). Local studies of hybrid supply systems have examined generation economics in northern Nigeria (Chen *et al.*, 2026; Dakhil *et al.*, 2026) but have not isolated the storage chemistry decision itself. This paper closes that gap with a deliberately transparent comparison. The contributions are threefold. First, a ten-year life-cycle cost model is formulated for a representative small enterprise backup system under three outage regimes spanning reported Nigerian conditions, with every parameter stated and sourced. Second, service life is treated honestly for the tropics: lead-acid calendar life is derated for a thirty degree Celsius operating ambient using the established halving of life per ten-degree rise, which proves to be the decisive mechanism in the result. Third, net present cost, levelised cost of storage and a breakeven lithium price are reported with a one-at-a-time sensitivity analysis, and every parameter is stated so that any reader can rerun the comparison under their own prices and outage conditions. The study is analytical: it uses manufacturer-class parameters and literature ageing models rather than measurements on fielded banks, a limitation examined in Section 3.7.

MATERIALS AND METHODS

2.1 Model Framework

Fig. 1 shows the structure of the comparison. Three inputs feed the model: an outage regime, a representative enterprise backup load, and a battery parameter set for each chemistry. The bank is sized so that one day of outage energy can be served within the chemistry appropriate depth of discharge. Service life is the lesser of the cycle-limited life and the thermally derated calendar life. Discounted cash flows over a ten-year horizon then accumulate the initial purchase, replacements as each bank expires, annual maintenance, and the cost of the energy dissipated in round-trip losses, yielding the net present cost and, on division by discounted energy throughput, the levelised cost of storage (Julch, 2016; Schmidt *et al.*, 2019).

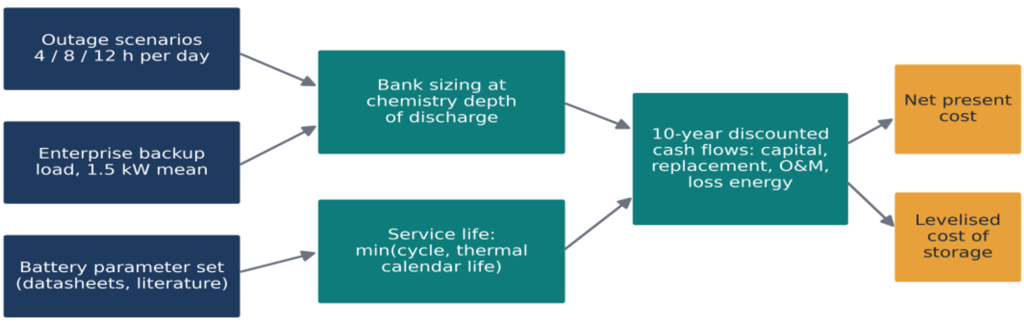

Fig. 1 Structure of the life-cycle cost comparison

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2.2 Outage Regimes and Enterprise Load

Rather than tie the analysis to any single measured feeder, the model spans the reported range of Nigerian supply conditions with three regimes: a Light regime of four hours of outage per day, a Moderate regime of eight hours, and a Severe regime of twelve hours, each assumed to draw one full battery cycle per day, consistent with the near-daily outage frequencies documented for Nigerian firms (World Bank, 2014). The representative enterprise carries a mean backup load of 1.5 kW, typical of a small office, retail or pharmacy load of lighting, fans, refrigeration and point-of-sale equipment, giving daily backup energies of 6, 12 and 18 kWh in the three regimes. Table-1 lists the resulting bank sizes. Because both chemistries scale linearly with energy in this formulation, the levelised cost of storage is identical across regimes and the regimes differ in absolute cost; this scale invariance is a feature, since it lets a reader rescale the results to any enterprise size by simple proportion.

Table-1 Outage regimes and installed bank sizes

Regime	Outage (h/day)	Backup energy (kWh/day)	Lead-acid bank (kWh nominal)	Lithium bank (kWh nominal)
Light	4	6	12.0	7.5
Moderate	8	12	24.0	15.0
Severe	12	18	36.0	22.5

2.3 Battery Models and Thermal Derating

Table-2 states the parameter set. The tubular lead-acid bank operates at 50 percent depth of discharge with 82 percent round-trip efficiency and a reference cycle life of 1500 cycles, at the deep-cycle end of the range surveyed for this class (May *et al.*, 2018; Dufo-Lopez *et al.*, 2014). The lithium iron phosphate bank operates at 80 percent depth of discharge with 95 percent efficiency and a reference cycle life of 4000 cycles (Zubi *et al.*, 2018). The comparison is restricted to these two chemistries deliberately: iron phosphate dominates Nigerian stationary retail and offers better thermal stability in enclosed battery rooms than nickel manganese cobalt variants, whose characteristics suit mobility better than daily-cycled stationary duty (Zubi *et al.*, 2018). Fig. 2 shows the cycle life against depth of discharge relations used, of the standard inverse-power form anchored at each chemistry reference point. Calendar life is 5 years for lead-acid and 10 years for lithium at a 25-degree Celsius reference. The critical adjustment is thermal: lead-acid ageing approximately doubles for each ten degrees rise in operating temperature, a recognised engineering approximation of the underlying Arrhenius kinetics rather than a universal law (Coccato *et al.*, 2025; Kuznetsov et al., 2026), so at the 30 degrees mean ambient assumed for enclosed Nigerian battery rooms the effective lead-acid calendar life falls to about 3.5 years. Lithium iron phosphate calendar ageing is far less temperature sensitive over this range: the Arrhenius fit of the commercial cell characterisation by Naumann *et al.* (2018) implies roughly 15 to 20 percent faster calendar fade at 30 than at 25 degrees, the basis of the 15 percent derating assigned at the same ambient. With daily cycling, the governing life is calendar-limited for both chemistries: 3.5 years for lead-acid against a cycle-limited 4.1, and 8.5 years for lithium against a cycle-limited 11.0.

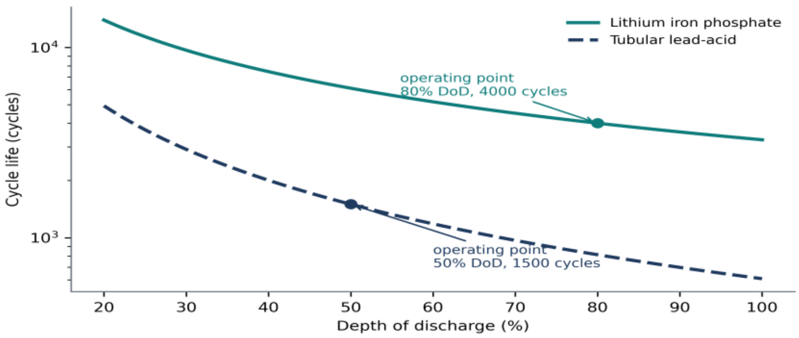

Fig. 2 Cycle life against depth of discharge relations used in the model, with the operating point of each chemistry

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Table-2 Model parameters (prices are indicative values; the lithium price is a deliberately conservative upper bound relative to the Table 3 survey)

Parameter	Tubular lead-acid	Lithium iron phosphate	Source
Usable depth of discharge	50%	80%	May *et al.* (2018); Zubi *et al.* (2018)
Round-trip efficiency	82%	95%	May *et al.* (2018); Zubi *et al.* (2018)
Reference cycle life	1500 at 50% DoD	4000 at 80% DoD	Dufo-Lopez *et al.* (2014); Zubi *et al.* (2018)
Calendar life at 25 °C	5 years	10 years	May et al. (2018); Zubi *et al.* (2018)
Thermal derating at 30 °C	life halves per +10 °C	15% reduction	Ruetschi (2004)
Installed price	130 $/kWh	300 $/kWh	Indicative market values
Annual maintenance	2% of capital	0.5% of capital	Design assumption
Charging energy price	0.10 $/kWh (solar)	0.10 $/kWh (solar)	Indicative
Discount rate / horizon	10% real / 10 years	10% real / 10 years	Design assumption

The 30 degree Celsius operating assumption is grounded in national climatology. Satellite-derived climate records place annual mean air temperature near 27 degrees on the southern coast at Lagos and Port Harcourt and around 28 to 29 degrees in the far north-west around Sokoto, adjacent to the study region, with northern dry-season maxima routinely exceeding 40 degrees (NASA, 2026; Ohunakin *et al.*, 2014). Enclosed battery rooms sit several degrees above ambient once inverter losses and restricted ventilation are added, so a 30 degree mean operating temperature is representative across both the humid south and the semi-arid north, and conservative for northern hot-season operation, where the thermal penalty on lead-acid would be harsher than modelled. Fig. 3 assembles the argument graphically, with monthly profiles of climate normal class drawn from the same satellite record (NASA, 2026): representative monthly ambient profiles for the two zones, an assumed enclosure rise band of 3 to 6 degrees over the northern profile pending field logging, and the model assumption, which passes through the band for most of the year and below it in the northern hot season.

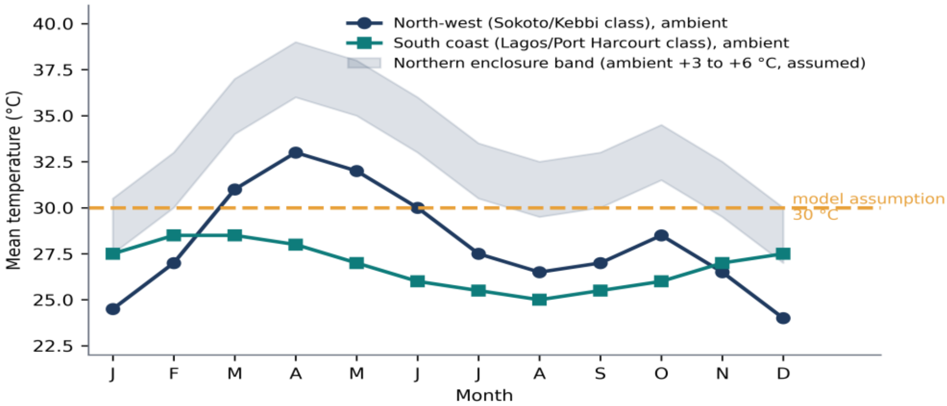

Fig. 3 Representative monthly mean ambient temperatures for northern and southern Nigeria with an assumed enclosure temperature rise band and the 30-degree model assumption

The battery parameters represent quality commercial products and individual manufacturers will differ. A survey of listed Nigerian distributor prices conducted in early July 2026, covering lithium iron phosphate packs of 5 to 25 kWh from brands widely sold locally such as Felicity Solar, found advertised prices clustering between roughly 100000 and 276000 naira per kilowatt hour depending on pack size, about 75 to 200 United States dollars at the prevailing official exchange rate near 1375 naira per dollar; Table 3 records the listings. By July 2026 the official and parallel exchange rates had converged to within about one percent, so the conversion is insensitive to channel; in periods of wider divergence, dollar-denominated prices of both chemistries scale together, leaving the comparison ordering unchanged. The same listings advertise 90 to 95 percent usable depth of discharge, upwards of 6000 rated cycles

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and warranties of five years, with some premium lines extending to seven. Two consequences follow. First, the 300-dollar installed price assumed here is deliberately conservative, sitting well above current listings, so the modelled lithium advantage understates the market reality. Second, the higher cycle ratings leave the results unchanged, because under daily cycling the model is calendar limited rather than cycle limited, while the warranty terms independently corroborate a calendar life of at least the warranted five to seven years against the 8.5 years assumed.

Table-3 Surveyed Nigerian distributor listings, early July 2026 (advertised single-unit retail prices; per-kilowatt-hour values rounded)

Product class	Capacity	Listed price (naira)	Naira per kWh
Felicity lithium, 24 V	5 kWh	1050000 to 1380000	210000 to 276000
Felicity lithium, 51.2 V	10 kWh	2650000	265000
Felicity lithium, 48 V	15 kWh	2300000 to 3305000	153000 to 220000
Felicity lithium, 48 V (promotional)	25 kWh	2495900	100000
Lithium, 12 V 200 Ah, assorted brands	2.4 kWh	315000 to 470000	131000 to 196000
Gel/tubular lead-acid, 12 V 200 Ah	2.4 kWh	about 300000	about 125000

Three further parameter choices deserve explicit justification. The maintenance rates of 2 and 0.5 percent of capital per year reflect the recurring watering, equalisation charging and specific gravity checking that flooded tubular batteries require and managed lithium packs do not (May *et al.*, 2018); valve-regulated and gel variants would reduce this burden at the cost of shorter deep-cycle life, and Section 3.4 shows the result is insensitive to halving the differential. The installed prices denote the delivered bank within Nigeria, inclusive of the integrated battery management system on the lithium side, and exclusive of import duty swings, which the breakeven analysis addresses directly. The charging energy price of 0.10 dollars per kilowatt hour sits within both the Nigerian solar levelised cost range and commercial grid tariff bands, so the same figure serves solar and grid-assisted charging; the sensitivity range of 0.05 to 0.20 dollars spans both regimes. It should be emphasised that all climatic and price inputs used here are secondary data, drawn from satellite climate records and advertised distributor listings respectively, and not from on-site field measurement; their cross-validation and eventual replacement by logged field values are addressed in Section 3.3 and Section 3.7.

2.4 Cost Formulation

The model reduces to five relations. The installed bank energy follows from the daily backup energy and the chemistry depth of discharge as

$$E_{nom} = \frac{E_{day}}{DoD} \tag{1}$$

and cycle life at the operating depth of discharge takes the standard inverse power form anchored at the reference point,

$$N_{cyc}(DoD) = N_{ref}\left(\frac{DoD_{ref}}{DoD}\right)^{k} \tag{2}$$

with k of 1.3 for lead-acid and 0.9 for lithium iron phosphate. Service life is the lesser of the cycle-limited and thermally derated calendar life,

$$L = min\left(\frac{N_{cyc}}{365}, L_{cal} \cdot f_T\right) \tag{3b}$$

$$f_T = 0.5^{\frac{T-25}{10}} \; for\ lead-acid; \quad f_T = 0.85\ at\ 30\ °C\ for\ lithium\ iron\ phosphate \tag{3a}$$

The net present cost accumulates bank purchases at each service life interval with a linear salvage credit S for the unused fraction u of the final bank, plus annual maintenance and loss energy streams,

$$NPC = \sum_j C_{bank}(1+r)^{-t_j} - S + \sum_{t=1}^{H}(C_{om} + C_{loss})(1+r)^{-t} \tag{4a}$$

$$S = u \cdot C_{bank}(1+r)^{-H}, \; u = unused\ fraction\ of\ the\ final\ bank\ at\ the\ horizon \tag{4b}$$

and the levelised cost of storage divides by discounted energy delivered to the load; round-trip losses are costed in the numerator, so the quotient reads as the cost of each kilowatt hour actually served. All prices and rates are held constant in real terms; general inflation and exchange rate movement are excluded because they act on both chemistries proportionately and cancel from the comparison,

$$LCOS = \frac{NPC}{\sum_{t=1}^{H} 365 \cdot E_{day}(1+r)^{-t}} \quad (5)$$

For each chemistry and regime, the net present cost is therefore the sum of four discounted streams: the initial bank purchase; replacement purchases at each service-life interval, with a linear salvage credit at the horizon for the unused fraction of the final bank; annual maintenance charged as a fixed share of capital, reflecting the watering and equalisation burden of flooded lead-acid against the near-zero attention of a managed lithium pack; and the cost of loss energy, computed as the annual delivered energy multiplied by the round-trip shortfall and priced at the solar charging cost. The levelised cost of storage divides the net present cost by the discounted energy delivered over the horizon, following the standard formulation (Julch, 2016). The calculation workbook implementing equations (1) to (5) is available from the corresponding author on request. Inverter and photovoltaic array costs are excluded deliberately: they are common to both chemistries at this system scale and would only dilute the comparison. All computations follow directly from equations (1) to (5) and the parameter set of Table-2.

RESULTS AND DISCUSSION

3.1 Replacement Dynamics

Fig. 4 traces cumulative discounted cost through the horizon for the Moderate regime. The lead-acid trajectory starts lower, at 3120 against 4500 dollars of initial capital, and the two curves first cross when the first lead-acid replacement falls due at year 3.5. A second replacement at year 7.1 widens the gap, while the single lithium replacement at year 8.5 is largely returned through the salvage credit for its unused life at the horizon. The pattern makes the economics legible to a non-specialist buyer: lead-acid is not cheaper, it is merely paid for in instalments of roughly three and a half years, and the tropics shorten those instalments.

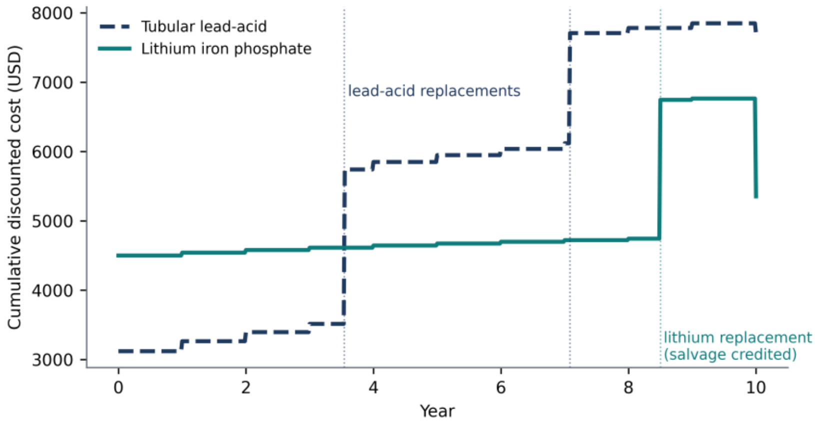

Fig. 4 Cumulative discounted cost over the horizon, Moderate regime

3.2 Net Present Cost and Levelised Cost of Storage

Fig. 5 assembles the ten-year net present cost for all six cases, decomposed into capital and replacement, maintenance, and loss energy, and Table-4 summarises the numbers. Lithium iron phosphate is cheaper in every regime by a stable margin of close to 31 percent: 2676 against 3853 dollars in the Light regime, 5353 against 7706 in the Moderate, and 8029 against 11558 in the Severe. The decomposition shows why. Lead-acid needs three bank purchases in ten years where lithium needs its initial bank plus one heavily salvage-offset replacement; lead-acid maintenance runs at four times the lithium rate on a larger bank; and its 18 percent round-trip shortfall against 5 percent buys measurably more loss energy every

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year. The levelised cost of storage settles at 0.199 dollars per kilowatt hour for lithium against 0.286 for lead-acid, values consistent in ordering and magnitude with international assessments of daily-cycled stationary storage (Schmidt *et al.*, 2019; IRENA, 2017; Cole and Frazier, 2019).

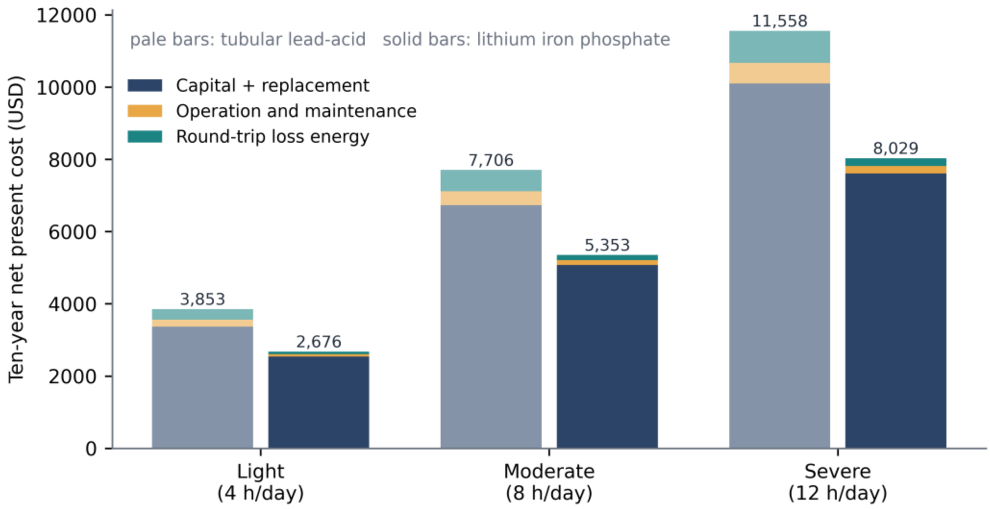

Fig. 5 Ten-year net present cost by regime and chemistry, decomposed by cost stream

Table-4 Summary of results

Regime	Chemistry	Bank (kWh)	Banks	NPC ($)	LCOS ($/kWh)
Light	Lead-acid	12.0	3	3853	0.286
Light	**Lithium**	**7.5**	**2**	**2676**	**0.199**
Moderate	Lead-acid	24.0	3	7706	0.286
Moderate	**Lithium**	**15.0**	**2**	**5353**	**0.199**
Severe	Lead-acid	36.0	3	11558	0.286
Severe	**Lithium**	**22.5**	**2**	**8029**	**0.199**

Chemistry labels abbreviate tubular lead-acid and lithium iron phosphate; the lower-cost chemistry is shown in bold.

3.3 Model Validation

Because the model is analytical, its outputs are cross-checked against independent published and industry data rather than against measurements on fielded banks. First, the modelled levelised cost of storage, 0.199 dollars per kilowatt hour for lithium iron phosphate and 0.286 for tubular lead-acid, is of the same order of magnitude as, and preserves the same chemistry ordering reported in, the international assessments of daily-cycled stationary storage by Schmidt *et al.* (2019), IRENA (2017) and Cole and Frazier (2019). Second, the modelled lithium calendar life of 8.5 years is corroborated independently by the five- to seven-year manufacturer warranties advertised in the July 2026 Nigerian distributor survey of Table 3, which provide a warranty-backed lower bound consistent with the assumption. Third, the reference cycle lives, depths of discharge and round-trip efficiencies applied to both chemistries lie within the manufacturer and review values of May *et al.* (2018), Dufo-Lopez *et al.* (2014) and Zubi *et al.* (2018). Agreement across these academic, agency and commercial sources supports the credibility of the deterministic results, while the field campaign outlined in Section 3.7 remains the necessary next step to confirm the thermal-derating assumption under measured Nigerian operating conditions.

3.4 Sensitivity and Breakeven

Fig. 6 perturbs the Moderate-regime lithium advantage of 2353 dollars one parameter at a time. The advantage is most sensitive to the lead-acid service life itself: if heat, maintenance quality or product grade move the effective life by 30 percent, the advantage swings between about 1060 and 4750 dollars, yet never approaches parity. A 30 percent movement in lithium price spans 790 to 3920 dollars of

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advantage. Raising the discount rate to 15 percent narrows the gap, as it penalises the lithium pattern of paying more up front, while cheap charging energy matters little because loss energy is the smallest stream. In no examined case does the advantage cross zero. Solving explicitly for parity, lithium remains the cheaper chemistry until its installed price exceeds about 435 dollars per kilowatt hour, some 45 percent above the assumed 300, a comfortable margin against Nigerian landing cost volatility. Three further point checks respond to conditions a Nigerian buyer may recognise. At a 20 percent real discount rate, reflecting the high cost of enterprise capital in Nigeria, the advantage narrows to about 1150 dollars but persists. Halving the maintenance differential, as a well-kept valve-regulated bank might achieve, trims the advantage by under 200 dollars. And charging a 200-dollar premium for a lithium-compatible inverter, where an existing installation lacks one, still leaves an advantage above 2150 dollars. Set against the distributor survey of Section 2.3, the breakeven carries a wide cushion: listed Nigerian lithium prices of roughly 75 to 200 dollars per kilowatt hour sit at under a fifth to under half of the 435 dollar parity price.

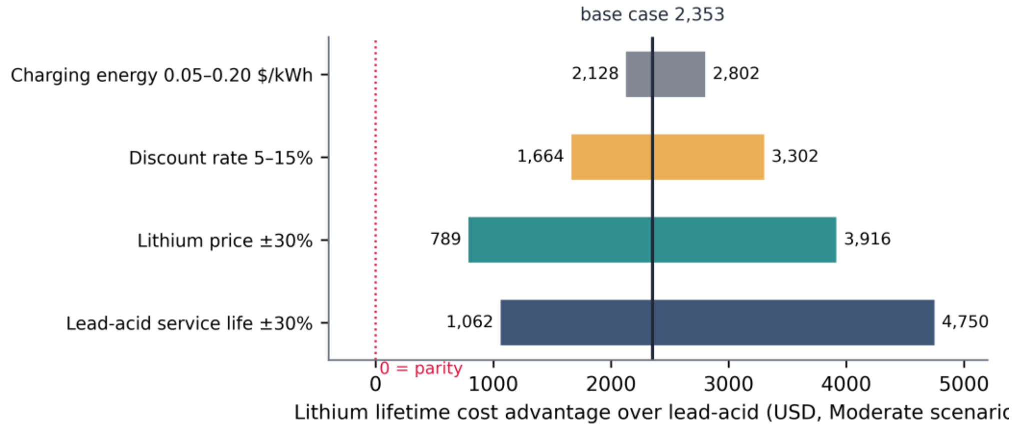

Fig. 6 One-at-a-time sensitivity of the lithium cost advantage, Moderate regime

3.5 Probabilistic Analysis

One-at-a-time perturbation cannot capture parameters moving together, so the deterministic analysis is completed with a Monte Carlo experiment of ten thousand draws for the Moderate regime. Each draw samples the discount rate and charging energy price uniformly across 5 to 20 percent and 0.05 to 0.20 dollars per kilowatt hour respectively, samples the lithium price, lead-acid service life and lithium service life from triangular distributions of 30, 30 and 15 percent half-width centred on the base values, and adds a lithium-side inverter compatibility premium drawn uniformly between 0 and 500 dollars, all listed in full in Table-5. Fig. 7 shows the resulting distribution of the lithium advantage. The median is 1901 dollars, the mean 1991, with a 90 percent interval of 219 to 4085 dollars, and the advantage is positive in 97.3 percent of draws; the small adverse tail requires expensive lithium, a costly inverter change, long-lived lead-acid and dear capital simultaneously. The corresponding levelised cost distributions place lithium at a median of 0.216 against 0.306 dollars per kilowatt hour for lead-acid, with the two 90 percent intervals barely overlapping. The chemistry ordering is therefore not an artefact of point estimates.

Table-5 Monte Carlo input distributions (multipliers apply to the base values of Table-2)

Variable	Distribution	Minimum	Mode	Maximum
Real discount rate	Uniform	0.05	not applicable	0.20
Charging energy price ($/kWh)	Uniform	0.05	not applicable	0.20
Lithium price multiplier	Triangular	0.70	1.00	1.30
Lead-acid service life multiplier	Triangular	0.70	1.00	1.30

Lithium service life multiplier	Triangular	0.85	1.00	1.15
Inverter compatibility premium ($)	Uniform	0	not applicable	500

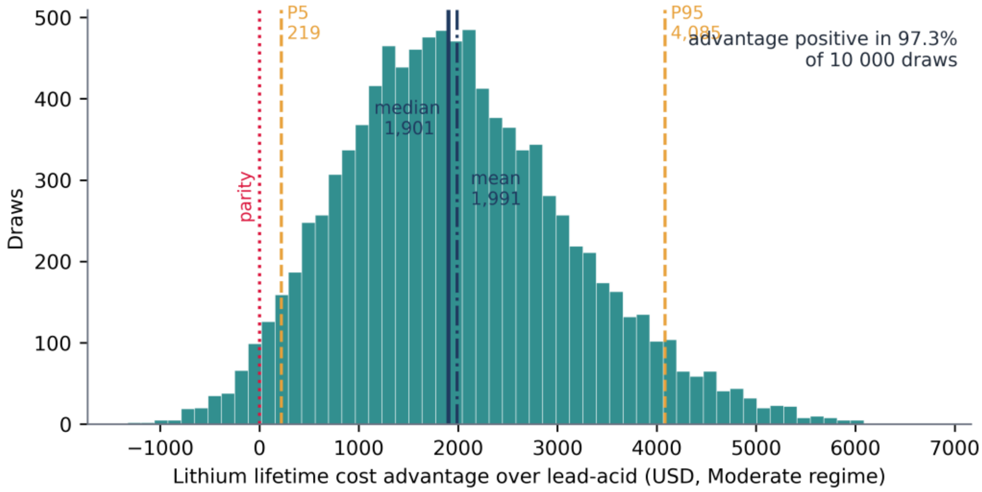

Fig. 7 Monte Carlo distribution of the lithium cost advantage over ten thousand parameter draws, Moderate regime

3.6 Practical Implications

Three practical readings follow. For an enterprise able to finance the higher initial outlay, lithium iron phosphate is the rational purchase across the entire plausible parameter space examined here, and the more severe the outage regime, the larger the absolute saving. For cash-constrained buyers, the result reframes the financing question: the roughly 2350 dollar Moderate-regime saving is the price currently being paid for spreading capital into lead-acid instalments, which suggests a role for vendor credit and pay-as-you-go structures around lithium banks. For installers, the thermal mechanism carries a design lesson independent of chemistry: battery room ventilation and shading directly extend lead-acid life, and every degree matters. The scale invariance of the levelised cost means these conclusions transfer unchanged to larger or smaller enterprises of similar daily cycling behaviour. One genuine lead-acid virtue survives the arithmetic: simplicity. A lithium pack depends on its battery management system, whose failure can disable an otherwise healthy bank, whereas a flooded tubular bank degrades gracefully and can be nursed by any competent technician. In locations without reliable technical support, that fault tolerance has a value the cost model does not capture. A buyer wanting a numerical margin for management system replacement risk can load the lithium capital with a 10 percent contingency, which trims the Moderate-regime advantage to roughly 1900 dollars without changing the ordering, and buyers in remote locations should weigh supplier warranty terms, confirm the local warranty claim route before purchase, and weigh service capability alongside the lifetime arithmetic presented here.

3.7 Limitations

Six limitations bound the claims. First, the study is analytical: parameters are manufacturer-class and literature values, not measurements on fielded Nigerian banks, and a field campaign logging bank temperature, cycling depth and failure ages is the natural continuation. Second, prices are indicative single-installation values in a market with volatile import costs; the stated parameter set lets any reader substitute current quotations through equations (1) to (5), and the breakeven price gives the decision boundary directly. Third, the outage regimes are stylised at one cycle per day; grids with clustered multi-day outages would shift sizing, though not the chemistry ordering, since deeper reserve requirements penalise the shallower-discharge chemistry further. Fourth, the model excludes end-of-

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life value: lead-acid enjoys an established Nigerian recycling market while lithium recovery remains nascent, a residual-value effect that favours lead-acid but bounded: crediting scrap recovery at each lead-acid retirement, parity would require recovering about 47 percent of the purchase price per bank, far above the 15 to 20 percent that Nigerian scrap channels typically return, and at a generous 20 percent the Moderate-regime lithium advantage still stands near 1350 dollars. Fifth, banks are replaced instantaneously at rated end of life; real batteries fade progressively and owners often run them beyond rating at reduced capacity, which delays expenditure but degrades backup service, an effect a capacity-fade model would capture. Sixth, the one-cycle-per-day regimes idealise real duty: Nigerian supply often produces partial and clustered cycling, and sustained partial state of charge operation promotes sulphation in lead-acid, a mechanism that would move the comparison further in favour of lithium rather than against it.

CONTRIBUTION TO KNOWLEDGE

This study makes three contributions to knowledge. First, it formulates a fully transparent ten-year life-cycle cost model for a representative small-enterprise solar backup system under three outage regimes spanning reported Nigerian conditions, with every parameter stated and sourced. Second, it treats battery service life honestly for the tropics by derating lead-acid calendar life for a thirty-degree-Celsius operating ambient, and shows that thermal ageing, rather than cycle count, is the decisive mechanism governing the storage decision for daily-cycled banks. Third, it reports net present cost, levelised cost of storage and a breakeven lithium price, supported by one-at-a-time and Monte Carlo sensitivity analyses and validated against independent international benchmarks, thereby giving Nigerian enterprises, installers and policymakers a reproducible basis for choosing between the two dominant storage chemistries.

CONCLUSION

This paper has compared lithium iron phosphate and tubular lead-acid storage for small enterprise solar backup in Nigeria with a fully reproducible ten-year life-cycle cost model spanning outage regimes of four, eight and twelve hours per day. Lithium iron phosphate delivers the lower net present cost in every regime by close to 31 percent, with a levelised cost of stored electricity of 0.199 against 0.286 dollars per kilowatt hour, and the advantage survives 30 percent perturbations of every major parameter as well as a ten thousand draw Monte Carlo over all of them jointly, including an inverter compatibility premium, in which lithium remains cheaper in 97.3 percent of cases, reaching parity only if installed lithium prices rise beyond about 435 dollars per kilowatt hour. The decisive mechanism is tropical temperature, which shortens effective lead-acid calendar life to roughly 3.5 years and forces two replacements within the horizon. The practical message for Nigerian enterprises is direct: where financing permits, the higher lithium purchase price buys the cheaper decade of backup power, and where it does not, the quantified gap defines the value of credit structures that make lithium accessible. Field verification of bank temperatures, cycling behaviour and realised lead-acid failure ages in Kebbi State installations is the planned next stage of the work, alongside three natural extensions: degradation modelling under measured Nigerian duty cycles, optimisation of battery room ventilation as a low-cost life-extension measure, and the economics of end-of-life recycling for both chemistries.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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