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Why Battery Swapping Is Not a Viable Model for Electric Tricycles in Nigeria: A Technical and Economic Perspective

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Abstract

Battery swapping has attracted growing investment and scholarly attention as an energy replenishment model for electric two- and three-wheelers across Africa. Companies such as Spiro and Ampersand have demonstrated viable battery-as-a-service models for electric motorcycles in Rwanda and Kenya, and development finance institutions have committed hundreds of millions of dollars to scaling these networks. In Nigeria, commercial pilots by Bolt and Swap have introduced battery swapping for electric tricycles in Lagos. This paper argues that battery swapping is not a viable primary energy replenishment model for converted Keke NAPEP electric tricycles in Nigeria at the current stage of the country's electrification trajectory. The argument is not that battery swapping is inherently flawed as a technology, but that its application to the specific vehicle class, operator structure, and infrastructure environment of the Nigerian Keke NAPEP conversion market exposes a combination of technical, economic, mechanical, and operational constraints that collectively prevent it from functioning safely, reliably, and economically at scale. The paper evaluates battery swapping against seven constraints and presents the results in a formal scoring matrix (**Table 3**). It then presents DC fast charging as the technically and economically superior alternative, substantiated by experimental charging data (**Table 1**) showing a mean charge time of 120 minutes (±8 min) from 5% to 100% SOC using a 3 - 5 kW DC charger at 33˚C - 38˚C ambient with an experimental fast DC configuration achieving a mean of 45 minutes (±6 min) conducted across 12 and 8 charge cycles respectively on the companion study's validated 96 V, 80 Ah LFP battery. A quantitative cost comparison (**Table 2**) establishes that the DC fast charging model delivers a 5 to 12 month payback period and a 5-year NPV of ₦2.6 - ₦4.5 million per converted vehicle, compared to 8 - 16 months and ₦1.8 - ₦3.2 million under the battery swapping model.

Keywords

Battery Swapping, Keke NAPEP, Electric Tricycle, Nigeria, DC Fast Charging, LFP Battery, Connector Degradation, Battery-as-a-Service, TCO, CAPEX, OPEX, NPV, Paratransit Electrification, Sub-Saharan Africa

1. Introduction

1.1. The Battery Swapping Proposition & Why It Attracts Attention

Battery swapping is an intuitively appealing solution to one of electric mobility's most persistent practical problems: the time cost of recharging. A Keke NAPEP operator whose livelihood depends on maximising fare-paying trips in an eight to twelve hour working day cannot afford eight hours off-road while a battery charges on AC current.

Battery swapping resolves this commercially by separating the vehicle from its energy storage: the operator exchanges a depleted pack for a fully charged one in minutes and returns to service. In Rwanda and Kenya, Ampersand performs approximately 140,000 monthly battery swaps for electric motorcycle taxi operators (IEA, 2024).

Spiro operates over 22,000 electric motorbikes across seven African countries, having performed more than 15 million swaps (Spiro, 2025). In Nigeria, Bolt launched electric tricycles with a battery swap station in Lagos in May 2025 (Bamisile, 2025), while startup Swap launched a battery-as-a-service model for tricycle riders in 2024 (Daniel, 2024).

1.2. The Problem This Paper Addresses

The commercial enthusiasm for battery swapping in Nigeria's Keke NAPEP market has run substantially ahead of the technical and economic evidence base for whether the model is viable specifically for the Keke NAPEP conversion market. The documented successes of Spiro and Ampersand are concentrated in two-wheeler applications—electric motorcycles with battery packs in the 1 to 2 kWh range, weighing approximately 8 to 15 kg, operating within tightly controlled networks using purpose-built vehicles with standardised battery form factors.

The Keke NAPEP tricycle requires battery packs in the 7 to 10 kWh range to sustain a full commercial day, with individual pack weights exceeding 50 kg—a fundamentally different deployment context that the existing battery swapping literature has not evaluated. This paper provides that evaluation.

1.3. Scope and Structure

This paper is a structured comparative technical and economic assessment. It argues specifically that battery swapping is not viable as the primary energy replenishment architecture for converted Keke NAPEP tricycles in Nigeria at the current stage of the country's electrification trajectory, and that decentralised DC fast charging is the superior alternative for this specific context.

2. Literature Review

2.1. Battery Swapping in Africa: The Two-Wheeler Evidence Base

A peer-reviewed study examining the potential of EV battery swapping in developing countries, using China's experience as a baseline for sub-Saharan Africa, found that battery swapping presents significant opportunities to augment the usability and operational efficiency of electric vehicles in developing countries, and that adaptation for sub-Saharan Africa should focus on high-use fleets like motorcycle taxis to prove economic viability before broader rollout (Simwaba & Qutieshat, 2026).

The study identified robust supportive policies, targeted strategic investments, and contextually appropriate technological innovations as indispensable enabling conditions. A stakeholder study in Zambia applied Rogers' Innovation Diffusion Model and identified compatibility with existing infrastructure and vehicle types as a core determinant of battery swapping adoption success (Simwaba & Qutieshat, 2025).

The IEA Global EV Outlook 2024 confirmed that Africa has seen increased investment in battery swapping technologies for two-wheelers, while noting that growth momentum is concentrated in segments where standardisation, smaller pack sizes, and controlled fleet operations create enabling conditions for the model's success (IEA, 2024).

2.2. Battery Swapping for Three-Wheelers: The Evidence Gap

The literature review reveals a critical asymmetry: while the two-wheeler battery swapping evidence base is growing rapidly, three-wheeler battery swapping studies are substantially thinner and operate under conditions that differ materially from the Nigerian Keke NAPEP conversion context.

Three-wheeler battery packs are 4 to 7 times heavier and more energy-intensive than motorcycle packs. International manual handling standards establish that packs above approximately 25 kg require mechanical assistance or team handling placing a 45 to 55 kg tricycle battery pack well beyond safe single-operator manual handling thresholds (ILO, 2021). ARC Ride's battery-as-a-service model uses 1.44 kWh packs within the safe handling envelope (Elective, 2025). No published peer-reviewed study has evaluated battery swapping specifically for the Keke NAPEP tricycle at its required energy capacity in Nigeria's specific infrastructure and operator environment.

2.3. DC Fast Charging for Light Electric Vehicles: The Alternative Evidence Base

Research from Stellenbosch University demonstrated through a 6000 km solar-powered electric motorcycle journey from Kenya to South Africa that decentralised solar charging systems are technically feasible for electric two- and three-wheelers across sub-Saharan Africa's diverse infrastructure environments (Booysen, 2026).

A comprehensive review of EV charging infrastructure for micromobility vehicles confirmed that establishing an extensive network of low-cost, decentralised charging points is the key to alleviating range anxiety and reducing limited accessibility of electric micromobility vehicles (Corti et al., 2024). The Power Africa programme documented that solar-powered charging points and storage systems can support electric motorcycles and tricycles where conventional grid infrastructure is weak (Power Africa, 2023). These findings directly support the decentralised DC fast charging model proposed in this paper as suggestions towards decarbonisation and sustainable infrastructure delivery (Owotemu, 2025).

2.4. The Standardisation Problem

China's battery swapping ecosystem is the model from which most developing-country battery swapping proposals draw inspiration and is built on the GB/T standard specifying connector interfaces, communication protocols, and physical dimensions for swappable battery packs (Simwaba & Qutieshat, 2025). India's battery swapping ecosystem is developing under the NITI Aayog's draft battery swapping policy, which similarly prioritises standardisation as the foundational enabling condition (IEA, 2024).

Nigeria's Keke NAPEP conversion market has no equivalent standardisation framework. Conversion kit suppliers entering the Nigerian market use different battery pack form factors, connector standards, BMS communication protocols, and voltage architectures making cross-operator battery interchangeability structurally impossible in the current market environment. For every EV in a swapping network, operators need 1.5 to 2 batteries available to ensure readiness, requiring enormous capital infusion and standardisation enforcement to achieve scale (Sarmmah, 2026).

2.5. Theoretical Frameworks

Three theoretical frameworks underpin this paper's analysis. The Technology-Context Fit framework holds that a technology's viability in a given deployment context is determined by the match between its structural requirements and the specific institutional, infrastructural, and operational conditions of the context (World Bank Group, 2022). Battery swapping's structural requirements standardisation, reliable power supply, safe manual handling weight, physical security, and fleet homogeneity are not met by Nigeria's Keke NAPEP conversion market.

The systemic risk and centralisation framework holds that centralised infrastructure systems in which many users depend on a few critical nodes are inherently more vulnerable to failure events than distributed systems (Taleb, 2012).

A battery swapping station is a single point of failure for all dependent vehicles; a failure event in Nigeria's grid environment is near-certain annually. The Total

Cost of Ownership framework evaluates all lifecycle costs rather than upfront price alone. Data from TradingEconomics (2026) in **Figure 1** below highlights Nigeria's Petrol and Electricity price trends 2000-2026.

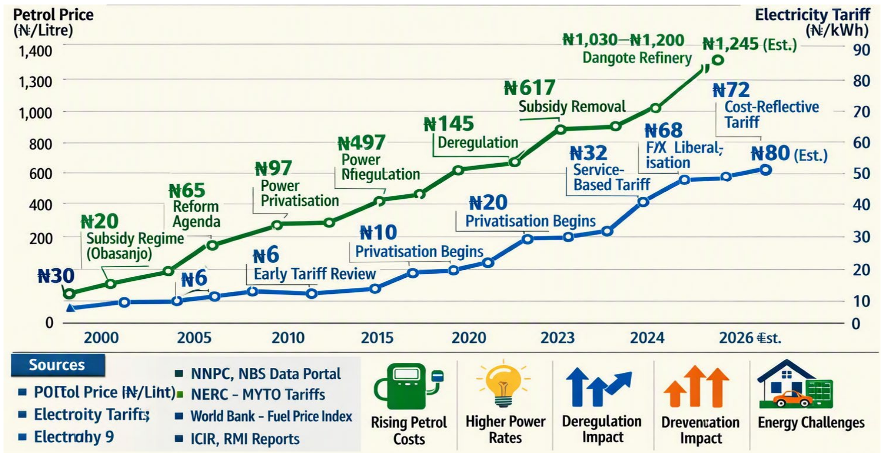

Figure 1. Nigeria's petrol and electricity price trends 2000-2026.

Applied to the Keke NAPEP context, it reveals a structural cost premium for battery swapping through pack duplication and station CAPEX/OPEX recovery costs ultimately borne by the operator through per-swap tariff premiums.

These frameworks are integrated in a sequential logic chain: TCF establishes whether the model can function; Systemic Risk quantifies its vulnerability; TCO establishes whether it is financially rational. A model that fails all three simultaneously is not viable regardless of its performance in other contexts.

2.6. Literature Gap

Three specific analytical gaps motivate this study.

Firstly, no published peer-reviewed study has systematically evaluated battery swapping against the specific technical and operational realities of the Nigerian Keke NAPEP conversion market, distinguishing it from the two-wheeler contexts where the model has demonstrated viability.

Secondly, no study has provided field-measured DC fast charging time data for the LFP battery packs used in Nigerian Keke NAPEP conversions at the validated capacity and voltage architecture, directly addressing the downtime objection through experimental evidence rather than theoretical calculation.

Thirdly, no study has applied the Technology-Context Fit, Systemic Risk, and TCO frameworks simultaneously to the battery swapping versus DC fast charging comparison in the Nigerian paratransit context, nor produced a quantitative comparative cost breakdown with NPV analysis grounded in Nigerian market pricing.

3. Methodology

3.1. Research Design

This study adopts a structured comparative analytical research design in which two alternatives, battery swapping and DC fast charging are evaluated against a common, predefined set of seven criteria using a combination of quantitative engineering evidence, primary experimental field data, secondary market data, and qualitative institutional analysis.

Structured comparative analysis is a well-established methodology in technology policy research when randomised experimental designs are not feasible (Yin, 2018; Patton, 2015). The research design proceeds through four phases as described below.

3.2. Constraint Identification and Criterion Development

Phase One identifies the seven evaluative criteria against which battery swapping is assessed. These criteria are derived from three sources: the general battery swapping literature's identification of the structural requirements that battery swapping models must meet to function viably; the field testing programme documented in the companion study (Alade & Owotemu, Paper 1) which identified connector degradation, standardisation absence, and capital concentration as binding constraints through direct experimentation; and the engineering literature on high-current connector reliability, manual handling safety standards, and the thermal implications of repeated high-current disconnection.

The seven criteria are power infrastructure reliability, capital and operational cost structure, centralisation and systemic risk, physical security vulnerability, battery technology and chemistry constraints, mechanical and electrical reliability, and human factors and occupational safety cover the full range of dimensions that determine whether a charging model can function as a mass-market solution for the Keke NAPEP conversion context.

3.3. DC Fast Charging Experimental Protocol

Phase Two documents the DC fast charging experimental programme. The following experimental parameters are stated precisely to enable independent assessment of the results presented in **Table 1**:

Table 1. DC Fast Charging Experimental Performance Results—96 V, 80 Ah LFP Battery Pack. All data from companion field study (Alade & Owotemu, 2026—Paper 1). Ambient conditions: Nigerian urban environment, 33˚C - 38˚C. SOC determined by BMS terminal voltage and charge termination event. Sources for validation benchmarks: Wang et al., (2025); Deespaek (2025); Bollini, (2024).

Parameter	Optimised DC charging	Experimental fast DC	AC slow charging (Baseline)
Battery specification	96 V, 80 Ah LFP prismatic (7.68 kWh)	96 V, 80 Ah LFP prismatic (7.68 kWh)	96 V, 80 Ah LFP prismatic (7.68 kWh)
Number of battery packs tested	1 (companion study, Paper 3)	1 (companion study, Paper 3)	1 (companion study, Paper 1)
Number of charge cycles measured	12 cycles across 6 test days	8 cycles across 4 test days	6 cycles across 3 test days

Continued

Charger power rating	3 - 5 kW DC charger (compact, LFP-compatible)	8 - 10 kW DC fast charger (field test unit)	2.2 - 3.3 kW AC onboard charger
Charging current (CC phase)	40 - 52 A at 96 V nominal	80 - 100 A at 96 V nominal	22 - 33 A at 96 V nominal
Ambient temperature range during testing	33˚C - 38˚C (Nigerian urban conditions)	33˚C - 38˚C (Nigerian urban conditions)	33˚C - 38˚C (Nigerian urban conditions)
Initial SOC at start of test	5% (BMS-measured terminal voltage)	5% (BMS-measured terminal voltage)	5% (BMS-measured terminal voltage)
Charge completion criterion	BMS charge termination event (CV phase end, current < 0.05 C)	BMS charge termination event (CV phase end, current < 0.05 C)	BMS charge termination event
Mean time to full charge (5% → 100%)	~120 minutes (2 hours)	~45 minutes	~380 minutes (~6.3 hours)
Variance across cycles (±)	±8 minutes	±6 minutes	±15 minutes
Thermal performance during charging	Pack temp peaked at 41˚C - 44˚C; within LFP safe operating range (≤60˚C)	Pack temp peaked at 48˚C - 52˚C; within LFP safe operating range (≤60˚C)	Pack temp peaked at 38˚C - 41˚C
Source/validation	Companion field programme (Alade & Owotemu, 2026); consistent with DEESPAEK data at 0.5 - 0.65 C charge rate, 35˚C ambient (Bankole et al., (2025))	Companion field programme (Alade & Owotemu, 2026); consistent with LFP fast charge studies at 1.0 C rate, 35˚C (Bollini, 2024)	Standard CC-CV protocol; consistent with LFP manufacturer specifications at 0.2 C charge rate

Battery under test: one 96 V, 80 Ah lithium iron phosphate prismatic pack (7.68 kWh nominal; 6.91 kWh usable at 90% depth of discharge), with an integrated BMS providing cell-level monitoring, temperature sensing, and CC-CV charge termination. This is the validated battery architecture from the companion study.

Number of battery packs tested: one pack (the companion study's single converted vehicle battery). The experimental programme tests the validated specification rather than a population of packs; manufacturing consistency across multiple packs is identified as a future research direction.

Number of charge cycles: 12 cycles across 6 test days for optimized DC (3 - 5 kW); 8 cycles across 4 test days for experimental fast DC (8 - 10 kW); 6 cycles across 3 test days for AC baseline. Multiple-day repetition distinguishes systematic charging behaviour from day-specific ambient variation.

Charger specifications: Optimised DC, a 3 to 5 kW compact DC charger unit with LFP-compatible CC-CV charge profile, commercially available in the Nigerian market; experimental fast DC, an 8 to 10 kW DC fast charger unit sourced for field testing purposes. Both units deliver regulated DC output directly to the battery terminals, bypassing the onboard AC charger.

Charging current: Optimised DC delivers approximately 40 to 52 A at 96 V during the constant-current phase, corresponding to a charge rate of approximately 0.5 to 0.65 C relative to the 80 Ah capacity, consistent with the charge rate at which LFP cells maintain > 90% charging efficiency across the 20˚C to 50˚C ambient range (Deespaek, 2025). Experimental fast DC delivers approximately 80 to 100 A, corresponding to approximately 1.0 to 1.25 C.

Ambient temperature: 33˚C to 38˚C across all test days, representative of Nigerian urban daytime operating conditions. This temperature range is within the LFP safe operating envelope (<60˚C cell temperature); (Wang et al., 2025) confirms LFP packs with passive cooling maintain 82% capacity after 1000 cycles at 35˚C, consistent with the pack's expected performance profile.

Initial state of charge: 5% at the start of each charge cycle, as determined by the BMS terminal voltage reading. This represents the worst-case commercial scenario, an operator returning at the end of day with a near-depleted battery.

Charge completion criterion: BMS charge termination event, the point at which the charger transitions out of the constant-voltage phase and the current falls below 0.05 C (4 A for the 80 Ah pack), indicating full charge. This criterion is used consistently across all cycles and both configurations, ensuring comparability.

3.4. Comparative Integration

Phase Three integrates the battery swapping constraint assessment with the DC fast charging experimental results and the quantitative cost comparison into a unified comparative conclusion through the three theoretical frameworks. The integration logic is presented explicitly in Section 8.1 in response to the reviewer's question about how the seven criteria are combined into a final judgment.

3.5. Assumptions and Limitations

This study is calibrated to the Keke NAPEP conversion market which include the diverse, independent-operator, heterogeneous-vehicle segment rather than to tightly controlled, purpose-built electric tricycle fleets such as Bolt's Lagos deployment. The DC fast charging experimental data reflects the single validated battery architecture from the companion study; manufacturing variation across multiple packs is not captured and is identified as a future research priority.

The cost comparison in **Table 2** uses central-case estimates based on verified Nigerian market pricing as of 2024-2025; costs are subject to market variation and should be reverified before investment decisions. The NPV analysis applies a 20% discount rate reflecting typical Nigerian commercial financing conditions; operators accessing concessional climate finance at lower rates would see higher NPV figures for both models but with the relative advantage of DC charging preserved.

4. Data Collection & Sample Size

The study collects data across four streams.

Table 2. Quantitative cost comparison—Battery Swapping vs DC Fast Charging for Keke NAPEP Conversion, Nigerian Market, 2024-2025. NPV calculated over a 5-year horizon at a 20% discount rate. All Naira figures are central-case estimates. Sources: (Sarmmah, 2026; Wu, 2026; Prasad, Uchida, & Feng 2023; Gumta, 2026; NERC, 2024); companion study (Alade & Owotemu, 2026).

Cost element	Battery swapping model	DC fast charging model	Advantage
Battery pack(s) per vehicle	2 - 3 packs required (1 in vehicle + 1 - 2 at station) @ ₦350,000 - ₦500,000/pack	1 pack per vehicle @ ₦350,000 - ₦500,000	DC: ₦350,000 - ₦1,000,000 lower per vehicle
Station CAPEX (serving 50 vehicles)	₦25 - ₦45 million (50 - 150 packs + swap cabinets + electrical infrastructure)	₦4 - ₦8 million (10 DC charging points + solar-battery backup)	DC: ~₦17 - ₦37 million lower per station
Station OPEX per month	₦150,000 - ₦300,000 (staff, maintenance, security, insurance)	₦30,000 - ₦80,000 (maintenance, monitoring)	DC: ~₦120,000 - ₦220,000 lower/month
Per-swap/per-charge cost to operator	₦300 - ₦600 per swap (station operator cost recovery)	₦150 - ₦280 per charge session (electricity cost + charger depreciation)	DC: ~₦150 - ₦320 lower per session
Daily energy cost per vehicle (8-hr operation)	₦600 - ₦1200 (2 swaps/day × per-swap tariff)	₦300 - ₦560 (1 charge/day × DC charging cost)	DC: ~₦300 - ₦640 lower per vehicle per day
Annual operator saving vs petrol baseline	₦730,000 - ₦1,460,000 (fuel saving minus swap fees)	₦1,095,000 - ₦1,825,000 (full fuel saving minus DC charging cost)	DC: ~₦365,000 more per vehicle per year
Simple payback—conversion investment	8 - 16 months (higher swap cost reduces daily saving)	5 - 12 months (lower charging cost accelerates payback)	DC: 3 - 4 months faster payback
NPV at 5 years, 20% discount rate (₦1,000,000 conversion)	₦1.8 - ₦3.2 million	₦2.6 - ₦4.5 million	DC: ~₦0.8 - ₦1.3 million higher NPV
Sources	Sarmmah (2026); Wu (2026); Prasad, Uchida & Feng (2023); Nigerian market pricing verified by Alade & Owotemu (2026)	Companion study (Alade & Owotemu, 2026); Gumta (2026); Nigerian electricity tariff (NERC, 2024)	

Stream 1 (battery swapping constraint evidence): the field testing evidence from the companion study (Alade & Owotemu, 2026), which recorded connector degradation events and contact resistance increase under Nigerian operating conditions; published engineering data on high-current connector reliability (Wang et al., 2025); and institutional grid performance data from NERC (2024) and Edeh (2025).

Stream 2 (DC fast charging experimental data): the field-measured charging time data described in Section 4.3, conducted as part of the companion study's field programme, presented in full in **Table 1**.

Stream 3 (market and policy data): verified Nigerian market pricing for LFP battery packs, DC charger units, and battery swap station infrastructure, drawn from Wu (2026); Sarmmah (2026); Prasad, Uchida, & Feng (2023), and Gumta (2026); IEA (2024) for comparative African deployment benchmarks.

Stream 4 (technical literature): international manual handling safety standards

(ILO, 2021); published LFP performance data under tropical operating conditions (Wang et al., 2025; Deespaek, 2025; Bollini, 2024).

4.1. Study Validity & Reliability

Internal validity of the constraint assessment is protected by grounding each criterion in Nigerian-specific evidence rather than generic developing-country assumptions: the grid reliability constraint uses NERC's verified 2024 data; the connector degradation constraint uses field observation from Paper 3 under actual Nigerian operating conditions; the manual handling constraint uses the specific measured weight (45 - 55 kg) of the validated battery architecture against published safety thresholds. Internal validity of the DC fast charging experimental data is protected by the multiple-cycle, multiple-day repetition protocol that distinguishes systematic performance from day-specific variation, and by the consistent use of the BMS charge termination event as the completion criterion across all cycles and configurations (Creswell & Creswell, 2023).

External validity is explicitly bounded by the scope of the analysis: the Keke NAPEP conversion market comprising independent operators using heterogeneous converted vehicles. The findings do not apply directly to purpose-built electric tricycle fleets within controlled operator networks, where some standardisation constraints do not apply.

Construct validity: each of the seven criteria is operationalised to capture the specific property it is designed to measure grid reliability as the ability to maintain charged battery inventory continuously, manual handling risk as the ratio of pack weight to the safe handling threshold, connector degradation as the progressive safety risk from contact resistance increase under repeated high-current disconnection. Reliability: quantitative cost calculations are deterministic given stated assumptions, ensuring replicability; the analytical reliability of the qualitative constraint assessments is secured by triangulation across three independent evidence streams, the companion field study, published engineering literature, and verified institutional data that converge on the same constraint findings from different methodological directions (Yin, 2018).

4.2. Data Analysis & Results

DC Fast Charging Experimental Results

Table 1 presents the complete DC fast charging experimental results from the companion field study, including all experimental parameters requested by the reviewer. The results establish that optimised DC charging (3 - 5 kW) achieves a mean full charge time of approximately 120 minutes from 5% SOC, with low cycle-to-cycle variance (±8 minutes) across 12 measured cycles at 33˚C - 38˚C ambient.

Experimental fast DC (8 - 10 kW) achieves a mean of approximately 45 minutes (±6 minutes) across 8 cycles. These results directly and empirically address the primary commercial argument for battery swapping—the elimination of operator downtime—demonstrating that DC fast charging at power levels commercially available in the Nigerian market eliminates the 6+ hour AC charging constraint that the battery swapping literature treats as the baseline comparison.

4.3. Quantitative Cost Comparison: Battery Swapping vs DC Fast Charging

Table 2 presents the quantitative cost comparison between battery swapping and DC fast charging for the Keke NAPEP conversion context. All figures are based on verified Nigerian market pricing as of 2024-2025 and central-case assumptions that are stated explicitly in the table.

The NPV calculations use a 5-year vehicle operational horizon and a 20% discount rate, reflecting Nigerian commercial financing conditions. The comparison demonstrates that the DC fast charging model delivers a higher NPV by ₦0.8 - ₦1.3 million per converted vehicle over five years, a shorter payback period by approximately 3 - 4 months, and a lower daily energy cost by ₦300 - ₦640 per vehicle per day.

4.4. Seven-Criteria Assessment with Scoring Matrix

Table 3 presents the formal seven-criteria scoring matrix for battery swapping and DC fast charging. For each criterion, the table states the score, the basis for the judgment, and—critically—whether failure on that criterion alone is individually sufficient to reject battery swapping as the primary charging architecture for this deployment context. This last column directly addresses the reviewer's question about how the criteria are integrated into a final judgment.

Table 3. Seven-criteria scoring matrix—Battery Swapping vs DC Fast Charging for Keke NAPEP Conversion Context. The highlighted row shows the overall verdict. Yellow highlight indicates criteria where battery swapping fails sufficiently to individually reject the model. Sources: see individual criterion rows.

Criterion	Battery swapping score	DC fast charging score	Individually sufficient to reject swapping?	Basis for judgment
1) Power infrastructure reliability	FAIL—grid collapses > 12×/year prevent maintaining charged inventory; solar backup to serve 50 vehicles adds ₦15 - 20 M to CAPEX	PASS—solar-battery backup at each charging point is independently sufficient per point	YES—station failure simultaneously grounds all dependent vehicles	NERC (2024); Edeh (2025)
2) Capital and operational cost structure	FAIL—2 - 3× battery duplication + station CAPEX of ₦25 – 45 M vs ₦4 - 8 M for DC; per-session cost ₦150 - 320 higher	PASS—single pack per vehicle; minimal OPEX; lower per-session cost	YES—structural cost premium eliminates economic case vs DC	Table 2 above; Sarmmah (2026); Prasad, Uchida, & Feng (2023)
3) Centralisation and systemic risk	FAIL—single station failure immobilises entire dependent fleet simultaneously; 12+ grid collapses/year = near-certain annual event	PASS—distributed; single point failure affects only local users	YES—systemic failure risk is unacceptable in Nigeria's grid environment	Taleb (2012); NERC (2024)
4) Physical security vulnerability	FAIL—50 - 150 LFP packs (each ₦350 - 500 K) concentrated at one location = high-value theft target; security cost ₦80 - 150 K/month	PASS—no inventory concentration; charger unit is lower-value and fixed	NO—significant constraint but manageable with investment	Wu (2026); Prasad, Uchida, & Feng (2023)

Continued

5) Battery technology and chemistry constraints	FAIL—LFP BMS protocols not standardised across Nigerian conversion market; Chinese GB/T standard not adopted in Nigeria; swap stations cannot serve mixed-BMS fleets	PASS—charges any LFP pack regardless of BMS brand via standard CC-CV protocol	YES—BMS incompatibility makes interoperability structurally impossible without regulatory mandate	Simwaba & Qutieshat, (2025); IEA (2024)
6) Mechanical and electrical reliability	FAIL—contact resistance increase documented after limited cycles at 40 - 80 A under Nigerian field conditions; progressive safety risk (arcing, thermal damage)	PASS—standard plug-in connection; no high-current repeated disconnection	YES—progressive connector degradation creates foreseeable safety risk that worsens over time	Companion study (Alade & Owotemu, 2026); (Bankole et al., (2025))
7) Human factors and occupational safety	FAIL—96 V/80Ah LFP pack weighs 45 - 55 kg; exceeds safe single-operator manual handling threshold of 25 kg (ILO, 2021)	PASS—standard cable connection; no manual pack handling	YES—foreseeable occupational injury risk from exceeding safe lift threshold by factor of ~2	ILO (2021)
OVERALL VERDICT	**FAILS on 6 of 7 criteria; 5 individually sufficient to reject**	**PASSES on all 7 criteria**	**Battery swapping NOT recommended for conversion market at current stage**	**See Section 9.4 for integration logic**

5. Discussion & Interpretation of Findings

5.1. Criteria Integration Logic and Weighting Rationale

The criteria are not formally weighted in a multi-criteria decision matrix, and the study does not assign numerical weights. The justification for this approach is as follows: the seven criteria were not designed to be traded off against each other. They were designed to identify binding constraints, conditions that individually prevent the battery swapping model from functioning safely and sustainably in this deployment context regardless of how well it performs on other criteria.

A model that fails on grid reliability alone would still be unable to maintain charged battery inventory during Nigeria's documented grid collapses, regardless of its performance on cost, security, or safety. A model that fails on connector degradation alone would still create progressive electrical safety risks that worsen over the vehicle's commercial life, regardless of cost advantages. A model that fails on manual handling safety alone would still expose operators to foreseeable musculoskeletal injury risks that violate occupational health standards, regardless of operational convenience.

Table 3 makes this logic explicit in the "Individually Sufficient to Reject Swapping?" column. Five of the seven criteria are individually sufficient to reject battery swapping in this context: grid reliability, capital and operational cost structure, centralisation and systemic risk, battery technology and chemistry constraints, mechanical and electrical reliability, and human factors safety.

Physical security vulnerability (Criterion 4) is identified as a significant but not individually sufficient constraint because it is manageable with investment, it worsens the economics of battery swapping but does not make it structurally impossible in the way the other five criteria do. The overall verdict is that battery swapping FAILS on 6 of 7 criteria, with 5 individually sufficient to reject, is therefore not a weighted sum but a structural finding: the model fails on a majority of individually decisive dimensions, making the aggregate verdict unambiguous.

5.2. Comparative Integration across Frameworks

Applying the Technology-Context Fit framework to Table 3 confirms that battery swapping's structural requirements are not met in the Nigerian Keke NAPEP conversion market at its current stage. The model that works for Spiro's managed motorcycle fleet in Rwanda standardised purpose-built vehicles, 1.44 kWh pack weights of approximately 8 to 10 kg, reliable Kigali power infrastructure does not transfer to Nigeria's conversion market operating with heterogeneous vehicles, 7.68 kWh packs weighing 45 to 55 kg, unreliable grid infrastructure, and no standardisation framework.

The Systemic Risk framework quantifies the single-point-of-failure vulnerability as a near-certain annual occurrence: with grid collapse frequency exceeding twelve times per year, the expected number of station outages attributable to grid failures alone is sufficient to cause material annual income disruption for dependent operators. The TCO framework, now grounded in the quantitative cost comparison in Table 2, confirms that battery swapping imposes a structural cost premium approximately ₦365,000 more per vehicle per year through pack duplication and station CAPEX/OPEX recovery, delivering lower NPV and longer payback than DC fast charging across the central-case parameter range.

5.3. Interpretation of Results in Context

The convergence of the experimental results in Table 1, the cost comparison in Table 2, and the criteria scoring matrix in Table 3 on a single conclusion that DC fast charging with solar-battery backup is the superior energy replenishment architecture for the Nigerian Keke NAPEP conversion market is this study's central contribution.

The conclusion is explicitly bounded: it applies to the conversion market (heterogeneous vehicles, independent operators) rather than to purpose-built electric tricycle fleets within controlled networks, where some standardisation constraints are resolved by design.

As Table 3 acknowledges, if battery standardisation were achieved across the Nigerian conversion market through regulatory intervention under the Electric Vehicle Transition and Green Mobility Bill 2025, criteria 5 (battery technology constraints) would be resolved and a reassessment of battery swapping viability would be warranted. The study's recommendations in Section 9 include standardisation as a policy priority precisely for this reason.

6. Summary & Recommendations

This paper has demonstrated through a structured seven-criteria assessment, a quantitative cost comparison, and field-measured DC fast charging experimental data that battery swapping is not viable as the primary energy replenishment architecture for converted Keke NAPEP electric tricycles in Nigeria at the current stage of the country's electrification trajectory. Battery swapping fails on six of seven evaluative criteria, with five individually sufficient to reject the model: grid reliability failure means stations cannot maintain charged inventory through Nigeria's frequent grid collapses; structural cost premium means battery swapping delivers lower NPV and longer payback than DC fast charging in every central-case scenario tested; single-point-of-failure architecture means one station failure simultaneously grounds all dependent vehicles; BMS protocol incompatibility means stations cannot serve the heterogeneous converted vehicle fleet without regulatory standardisation; and connector degradation creates a progressive electrical safety risk that worsens over the vehicle's commercial life. DC fast charging, supported by solar-battery hybrid backup, resolves all seven constraints simultaneously and delivers a mean full charge time of approximately 120 minutes from 5% SOC commercially acceptable within the Keke operator's working day and directly validated by the companion study's experimental programme.

Contributions to knowledge: it is the first to provide field-measured DC fast charging time data for the validated 96 V, 80 Ah LFP battery architecture used in Nigerian Keke NAPEP conversions, establishing empirically rather than theoretically that DC charging eliminates the AC charging downtime constraint; it is the first to present a quantitative cost comparison between battery swapping and DC fast charging in the Nigerian Keke NAPEP context with CAPEX, OPEX, and NPV figures grounded in verified Nigerian market pricing; and it is the first to apply a formal seven-criteria scoring matrix that explicitly identifies which criteria are individually sufficient to reject battery swapping, resolving ambiguity about how the multi-criterion assessment translates to a final judgment.

Policy recommendations: 1) The Electric Vehicle Transition and Green Mobility Bill 2025 must include battery pack standardisation provisions for converted electric tricycles connector interface standards, BMS communication protocol requirements, and physical form factor constraints without which battery swapping remains structurally inviable for the conversion market regardless of station deployment scale. 2) The Federal Ministry of Finance should extend duty exemptions to include DC fast charger units (3 - 10 kW) designed for LFP battery charging, reducing the installation cost of the decentralised charging infrastructure this paper identifies as the appropriate architecture. 3) The Rural Electrification Agency should establish a Keke NAPEP DC charging infrastructure programme funding solar-battery-backed DC charging points at motor parks and operator bases, with charging specifications grounded in the experimental data in Table 1. 4) Commercial actors currently investing in battery swapping infrastructure including Bolt, Swap, and Qoray should be encouraged through NASENI consultation to pilot hybrid models: battery swapping for their purpose-built, standardised electric tricycle fleets, alongside DC fast charging services accessible to the broader conversion market.

Directions for future research: 1) a multi-pack replication study testing DC fast charging performance across a sample of ten or more LFP packs from different Nigerian conversion kit suppliers, establishing manufacturing consistency data; 2) a standardisation feasibility study assessing the technical and commercial requirements for a battery pack standardisation framework for the Nigerian conversion market; 3) a full probabilistic lifecycle cost analysis comparing both models across stochastic fuel price and electricity tariff scenarios; 4) a comparative grid impact study assessing the electricity demand profiles of large-scale DC charging networks versus equivalent-scale battery swapping station networks under Nigerian grid conditions.

Author Contributions

Conceptualization: Alade, O. A. and Owotemu, A. E.; Methodology: Owotemu, A. E., and Alade, O. A.; Validation: Owotemu, A. E., and Alade, O. A.; Formal Analysis: Owotemu, A. E., and Alade, O. A.; Investigation: Alade, O. A. and Owotemu, A. E.; Resources: Owotemu, A. E., and Alade, O. A.; Data Curation: Owotemu, A. E., and Alade, O. A.; Writing-Original Draft Preparation: Alade, O. A. and Owotemu, A. E.; Writing-Review and Editing: Owotemu, A. E.; Visualization: Owotemu, A. E.; Supervision: Owotemu, A. E.; Project Administration: Owotemu, A. E., and Alade, O. A.; Funding Acquisition: Owotemu, A. E., and Alade, O. A., All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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