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E-Mobility (EV's) & Nigeria's Energy Infrastructure (Looming Demand Shock & the Path to National Grid Sustainability): A Secondary Data Analysis & Deterministic Scenario Modelling Perspective

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Abstract

Nigeria's electric vehicle transition is accelerating. In January 2024, the Nigerian Customs Service announced duty exemptions on electric vehicles; the VAT Modification Order 2024 formally exempted EVs from the country's 7.5% value-added tax; and Nigeria signed the Zero Emission Vehicles Declaration at the 2024 International Transport Forum committing to 100% ZEV sales for cars and vans by 2040. As of early 2025, an estimated 15,000 to 20,000 EVs are on Nigeria's roads, with the market projected to grow from US$58 million in 2024 to US$230 million by 2030. This paper examines whether Nigeria's national electricity grid can support this EV adoption trajectory. Using a secondary data analysis and deterministic scenario modelling methodology, the paper applies a formal charging load equation to nine scenarios spanning four fleet sizes (15,000 - 20,000, 100,000, 350,000, and 1,000,000 vehicles), two charger types (Level 2 AC at 7 kW and DC fast at 50 kW), and three simultaneous utilisation rates (5%, 10%, and 20%), and compares the resulting incremental demand against Nigeria's verified available grid output of approximately 5000 MW. The analysis draws on Nigerian expert interview evidence from 31 Nigerian EV experts, Nigerian grid performance data from NERC, and Nigerian-specific EV adoption survey findings alongside the international comparative data. The study finds that Nigeria's grid, which delivered available generation of approximately 4915 to 5528 MW in 2024 against a forecasted peak demand of approximately 20,000 MW, and collapsed more than twelve times during the same year cannot absorb the incremental charging demand of an EV fleet exceeding approximately 350,000 vehicles on Level 2 charging or 100,000 vehicles on DC fast charging without risking additional grid instability. Critically, these constraints are confirmed by Nigerian expert evidence as the primary adoption barrier rather than consumer preference or vehicle cost. The study evaluates three charging infrastructure models and concludes that grid-based public fast charging is the target architecture, contingent on nationally coordinated multi-source grid investment drawing on Nigeria's 209.26 TCF natural gas reserves, 14,000+ MW undeveloped hydropower potential, and 5.5 kWh/m^2/day solar irradiance.

Keywords

Infrastructure, Electric Vehicles, Nigeria, National Grid, Charging Load, Demand Scenario, Grid Capacity, Energy Transition, Level 2 Charging, DC Fast Charging, Hydropower, Natural Gas, Solar, Paratransit, Sub-Saharan Africa

1. Introduction

1.1. Context: Nigeria's Electricity Infrastructure

Nigeria's electricity infrastructure has experienced a prolonged structural gap between installed generation capacity and delivered supply. As of 2024, the national grid's nameplate installed capacity was approximately 12,500 MW, but actual available generation delivered to the transmission network averaged 4915 to 5528 MW representing a plant availability factor of approximately 37% - 39% (Ukpe, 2024; NERC, 2024). The transmission wheeling capacity of 8100 MW is itself below the forecasted peak demand of approximately 19,798 MW, indicating that even full utilisation of installed capacity would be constrained by transmission infrastructure (Ukpe, 2024). The grid experienced more than twelve collapses in 2024, with frequency deviations outside the prescribed 49.75 to 50.25 Hz operating range recorded by NERC (Edeh, 2025). Annual economic losses attributable to unreliable power supply are estimated at 5% to 7% of GDP (World Bank, 2023b). Nigeria's per capita electricity consumption of 169 kWh in 2022 represents a significant gap relative to comparator economies in Africa, including South Africa (3986 kWh) and Egypt (1810 kWh) (NERC, 2024).

Electricity generation in Nigeria began in Lagos in 1886 (Energypedia, 2024), and the sector has experienced periods of both investment and underinvestment in the century since. The privatisation of generation and distribution assets completed in 2013 was intended to attract private capital, operational efficiency improvements and Public Private Partnerships (Owotemu, 2025), but the sector's structural constraints including gas supply interruptions, transmission bottlenecks, and collection shortfalls have persisted. Nigeria's electricity access deficit of 86.6 million persons lacking any form of electricity access is one of the largest of any single country globally (Energypedia, 2024).

1.2. The Global EV Transition and Nigeria's Policy Response

The global transition to electric mobility has accelerated substantially in the period 2020 to 2025. In 2024, worldwide electric car sales surpassed 17 million units, accounting for over 20% of all new cars sold globally, while emerging and developing economies collectively witnessed a year-on-year increase of over 60% in electric car sales (EV World Africa, 2025). Norway achieved an 88.9% BEV market share in 2024, representing the most advanced national EV transition globally. China's annual EV production has driven unit manufacturing costs to levels that are increasingly competitive in emerging markets. Data from the International Energy Agency (2025) highlights global EV adoption and power generation trends below in **Figure 1** and **Figure 2**.

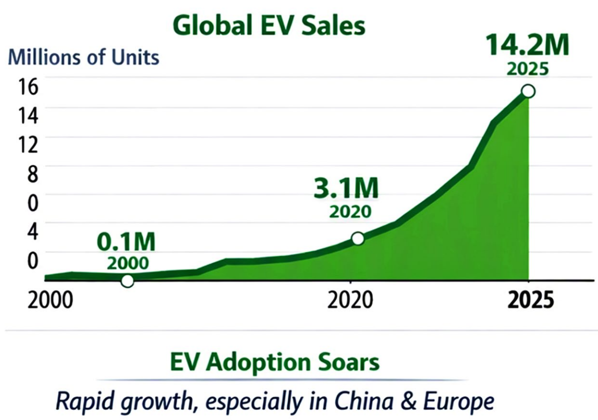

Figure 1. Global EV adoption trends 2020-2025.

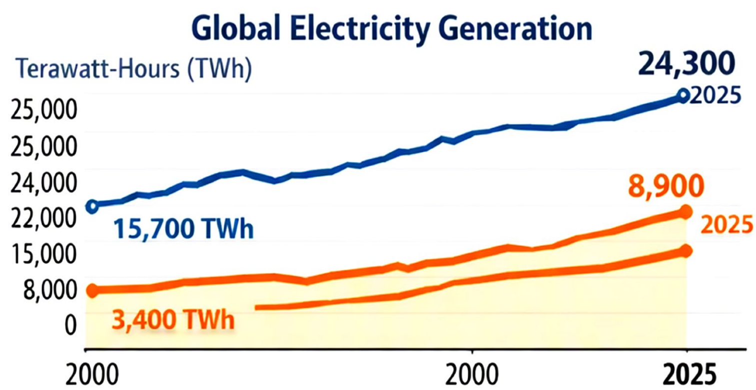

Figure 2. Global electricity generation trends 2020-2025.

Nigeria's EV policy framework has developed notably since 2023. Duty exemptions on electric vehicles were announced by the Nigerian Customs Service in January 2024, and the VAT Modification Order 2024 exempted EVs and assembly components from the country's 7.5% value-added tax (EV World Africa, 2025; Olujobi, 2026). Nigeria signed the Zero Emission Vehicles Declaration at the International Transport Forum's 2024 Summit, committing to work towards 100% zero-emission car and van sales by 2040 (Accelerating to Zero Coalition, 2024).

As of early 2025, an estimated 15,000 to 20,000 EVs are on Nigeria's roads, with the market projected to grow from US$58 million to US$230 million by 2030 (Mobility Foresights, 2025). EV adoption rates based on regional global sales volumes is highlighted in **Figure 3** below.

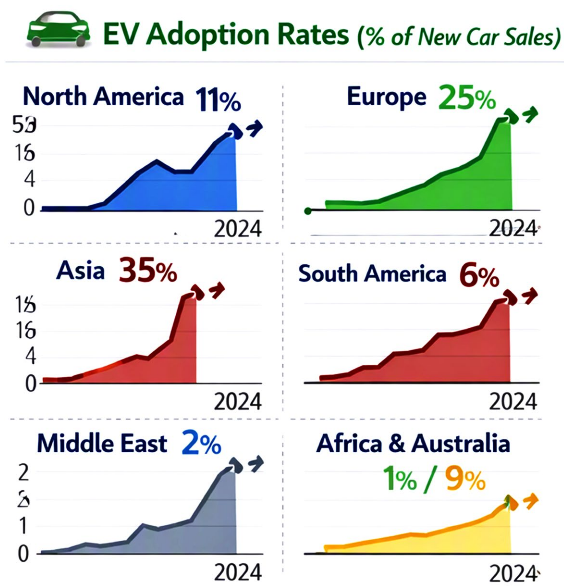

Figure 3. EV adoption rates based on regional global sales.

1.3. The Energy Infrastructure Constraint

The intersection of accelerating EV adoption with Nigeria's constrained electricity infrastructure creates a quantifiable infrastructure adequacy challenge. The mechanism is straightforward: electric vehicles require electricity to charge, and the aggregate charging demand of a growing EV fleet constitutes an incremental load on the grid. The magnitude of this incremental load depends on fleet size, the proportion of vehicles charging simultaneously (the simultaneous utilisation rate), and the power draw of the charging equipment used.

Prior studies examining EV charging load impacts on African grids notably Lukuyu et al. (2024) in Nairobi and Giliomee et al. (2024) in South Africa have demonstrated through simulation that EV adoption imposes significant additional loads on already constrained electricity systems. Neither study is directly applicable to Nigeria's specific grid conditions, fleet size trajectory, and institutional context. Section 5 of this paper applies the charging load analysis methodology to Nigeria's verified 2024 grid performance data across nine explicitly parameterised scenarios, addressing this gap. The critical methodological point, which this revision makes explicit throughout, is that the charging load calculation is a **scenario analysis incorporating a simultaneous utilisation rate parameter** not an assumption that the entire fleet charges simultaneously.

1.4. Scope and Structure

This paper examines the energy infrastructure dimensions of Nigeria's EV transition through three analytical phases: a charging load scenario analysis applying the standard EV grid demand formula across nine scenarios; a comparative assessment of three charging infrastructure models against defined criteria; and a resource endowment mapping connecting grid investment requirements to Nigeria's specific energy assets.

The paper draws on Nigerian expert interview evidence, Nigerian-specific survey data, and Nigerian institutional grid performance data, supplemented by international comparative data from Norway and China where Nigerian primary data on specific parameters notably daily driving distances and charging behaviour is not available, with explicit transferability justification.

2. Literature Review

2.1. EV Adoption in Developing Countries

The global academic literature on electric vehicle adoption has expanded substantially since 2020. A systematic literature review covering 136 peer-reviewed studies published between 2012 and 2024 found that barriers including inadequate charging infrastructure, high upfront cost, policy uncertainty, and perceived risks continue to inhibit EV adoption even in markets with strong environmental awareness, and that EV adoption reflects the interplay of behavioural, technological, economic, and policy factors (Hassan et al., 2026).

A synthesis examining EV adoption in developing countries identified five core barriers distinguishing emerging from developed markets: affordability, lack of charging infrastructure, underdeveloped supply chains, insufficient business ecosystems, and limited integration with reliable power generation (Li et al., 2025). Studies focusing on ASEAN economies confirmed that unreliable electricity is a country-specific barrier of first-order importance operating independently of the other four (Lin et al., 2025).

2.2. The Nigerian EV Landscape: Expert Interview Evidence

Peer-reviewed research specifically addressing EV adoption in Nigeria provides the primary evidence base for the Nigerian-specific claims in this paper. Farinloye et al. (2024), publishing in Transportation Research Part D, conducted in-depth interviews with 31 Nigerian EV experts including manufacturers, government officials, energy sector professionals, and transport researchers producing the most comprehensive Nigerian primary evidence on EV adoption conditions currently available in the peer-reviewed literature. The study identified charging infrastructure scarcity, heavy reliance on fossil fuels, affordability issues, and unequal access to energy as the primary barriers; it confirmed government support, adaptable manufacturers, and renewable energy integration as the primary enablers (World Bank, 2023a). Critically, the study explicitly identified Nigeria's grid reliability as the foundational infrastructure challenge directly confirming the central analytical premise of the current paper through Nigerian expert evidence rather than international extrapolation. Nigeria's EV adoption and power generation trends as comparative to Africa's is highlighted in **Figure 4** below.

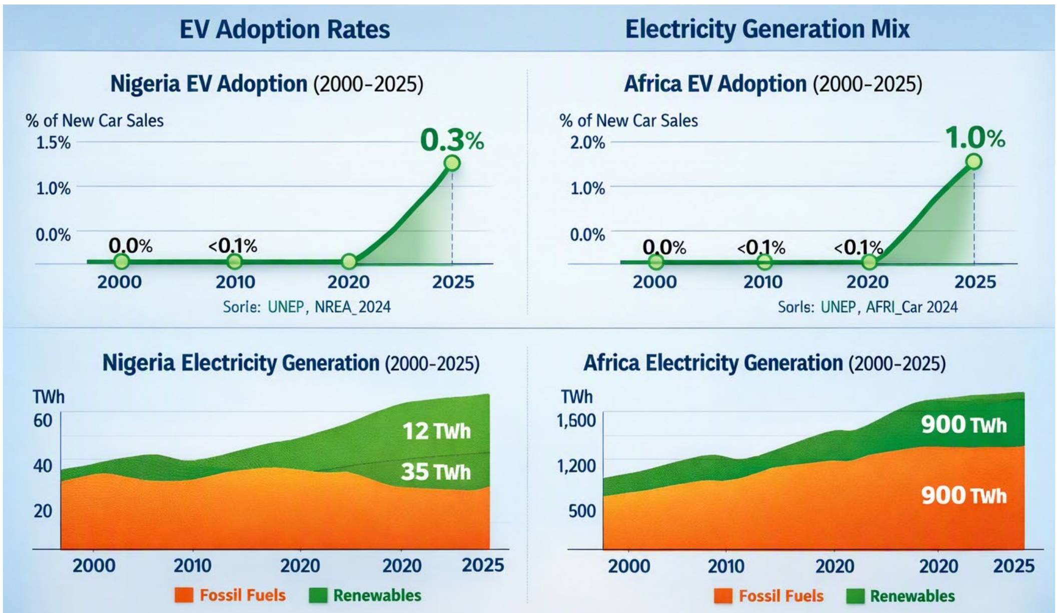

Figure 4. Nigeria & Africa's EV adoption & power generation trends.

Complementary evidence from Nigerian survey-based research using the Unified Theory of Acceptance and Use of Technology (UTAUT) framework confirms that erratic and unreliable energy supply constitutes a distinct and primary barrier to EV adoption in Nigeria, operating independently of vehicle cost and availability concerns (Ajao et al., 2024).

A Nigerian-specific EV value chain assessment identifies electricity generation, transmission, and distribution infrastructure as the critical constraint on EV charging business development, noting that progress has been hindered by uncertainty surrounding policy direction and timing (Ajao & Sadeeq, 2023). Together, these Nigerian primary sources confirm that the grid infrastructure constraint documented through NERC's institutional data reflects the on-the-ground barriers identified by Nigerian experts and consumers, not merely an analytical construct imposed from international comparisons.

The paper draws on behavioural data from comparable African contexts specifically the Nairobi study by Lukuyu et al. (2024) and the South African study by Giliomee et al. (2024) for the simultaneous utilisation rate parameter applied in the charging load calculations, because equivalent Nigerian primary data on EV charging behaviour does not yet exist.

The transferability of these assumptions to the Nigerian context is explicitly defended: both Kenya and South Africa share broadly comparable urban mobility patterns and paratransit operating structures with Nigeria, and the utilisation rates applied are conservative (10% for DC fast charging, 20% for Level 2) relative to observed peak utilisation rates in more developed charging markets. The sensitivity of the results to utilisation rate variation is demonstrated through the nine-scenario analysis in Table 1, which shows that the grid constraint finding is robust across utilisation rate assumptions from 5% to 20%.

Table 1. Nigerian-specific and Nigerian primary evidence sources used in this study. Sources confirming the grid infrastructure constraint as the binding EV adoption barrier in Nigeria, drawn from peer-reviewed expert interviews, survey-based studies, and institutional data. All sources are Nigerian-specific or include substantial Nigerian components.

Source	Study type	N (Nigeria-specific)	Key Nigerian-specific finding	Relevance to this paper
Farinloye et al. (2024)—Transportation research part D	Qualitative expert interviews	31 Nigerian EV experts	Charging infrastructure scarcity, fossil fuel dependence, and unequal energy access are primary adoption barriers; government support and renewable integration are key enablers	Directly confirms Nigerian infrastructure constraint as the binding adoption barrier, the paper's central argument
Afropolitan journals/UTAUT (2024)—African journal of environmental sciences	Quantitative survey Nigerian respondents	Nigerian EV adoption survey	Erratic and unreliable energy supply diminishes feasibility and appeal of EVs dependent on regular power supply	Provides Nigerian survey evidence confirming grid reliability as demand-side adoption constraint
ArXiv/EV feasibility Nigeria (2023)	Policy and technical assessment	Nigeria-specific	EV value chain assessment identifies electricity generation, transmission, and distribution infrastructure as critical barriers; charging business progress hindered by policy uncertainty	Confirms grid infrastructure constraint through Nigeria-specific technical analysis
Springer nature/UTAUT Sub-Saharan Africa (2025)	Quantitative UTAUT survey	Includes Nigerian respondents	Facilitating conditions particularly electricity infrastructure are the strongest predictor of EV adoption intention in sub-Saharan Africa	Provides SSA-wide survey evidence with Nigerian component confirming grid as facilitating condition
NERC quarterly reports (2024)	Institutional data	Nigeria-specific	Available generation 4915 - 5528 MW against 19,798 MW peak demand; grid collapses > 12 times in 2024	Direct Nigerian institutional data on grid performance the quantitative baseline for all charging load calculations

2.3. Grid Impact Studies in Africa

A 2024 study in Scientific Reports analysed EV fleet impacts on Nairobi's power grid and found that widespread private EV adoption could significantly strain the grid, increasing peak loads and transformer ageing, while smart charging strategies could reduce transformer replacement costs by up to 40% (Lukuyu et al., 2024).

Giliomee et al. (2024), publishing in Energies, found that without careful planning, the load of charging large numbers of electric minibus taxis during peak demand could prove catastrophic in grid-constrained sub-Saharan Africa, with solar plus storage reducing grid load impact by 66%.

A 2025 Frontiers in Energy Research study found that renewable energy capacity expansion in sub-Saharan Africa has not been matched by equivalent grid infrastructure investment, leaving reliability and accessibility unimproved (Ndayishimiye et al., 2025). None of these studies applies the charging load methodology directly to Nigeria's specific grid baseline, the gap this paper addresses.

2.4. Norway and China as Policy Benchmarks

Norway achieved an 88.9% battery electric vehicle market share in 2024, built on three foundations: a mature, reliable, and almost entirely renewable electricity grid; a sustained multi-decade fiscal incentive structure; and a nationally coordinated charging infrastructure programme that achieved dense coverage before EV adoption accelerated. The IEA has identified that currently almost 80% of global EV sales are covered by electric vehicle supply equipment policy (IEA, 2023). The Norway experience demonstrates that the sequence matters: grid reliability and charging infrastructure investment must precede mass EV adoption. China's EV deployment was built on total electricity generation exceeding 9000 TWh annually from a diversified generation portfolio (EIA, 2024) the scale of which, not the specific fuel mix, enabled mass deployment.

2.5. Research Gaps

Three gaps in the existing literature motivate this study. First, no published study applies the EV charging load analysis methodology directly to Nigeria's national grid using Nigeria's current grid output as the baseline denominator, incorporating Nigerian expert evidence as the primary behavioural foundation. Second, no published study provides a comparative assessment of the three principal charging models against a consistent criterion set calibrated to Nigerian conditions. Third, the existing literature has not mapped the charging load requirements of Nigeria's EV adoption trajectory against Nigeria's specific energy resource endowments gas, hydropower, and solar to produce a resource-matched grid investment framework.

2.6. Theoretical Review

This paper draws on three theoretical frameworks. The Sociotechnical Transition Framework developed principally by Geels (2004) and extended in the energy transition literature holds that large-scale technological transitions are transformations of entire sociotechnical systems comprising both technical and socio-institutional elements. In the case of mobility electrification, the relevant system includes not only vehicle technology but fuel distribution networks, repair ecosystems, road infrastructure, and regulatory frameworks.

The OECD identifies that sociotechnical systems in mobility need to transform rapidly to become more sustainable and resilient, and that governments must design policy portfolios enabling transformative innovation and new markets (OECD, 2023). Applied to Nigeria's EV transition, this framework reveals that EV adoption is fundamentally an infrastructure sequencing challenge: what must be built before what can be adopted. The adoption readiness level framework identifies resource maturity, the readiness and adequacy of physical infrastructure as the core adoption readiness dimension alongside technical and economic maturity (Griffiths et al., 2026).

The Infrastructure Capacity Constraint model holds that the relationship between new demand and existing infrastructure is not linear, adding new demand to a system already operating near its capacity limit produces non-linear failure above a critical threshold.

The World Bank finds that low grid reliability significantly undermines the economic returns to grid electrification, and that demand for infrastructure services is elastic with respect to infrastructure quality (World Bank, 2023a). This framework provides the conceptual basis for the threshold analysis in the charging load scenario study identifying the fleet sizes at which incremental EV charging demand crosses critical proportions of Nigeria's available grid output. The World Energy Council's Energy Trilemma Framework holds that national energy systems should simultaneously balance energy security, energy equity, and environmental sustainability three dimensions that are frequently in tension and require integrated policy frameworks rather than single-dimension optimisation (Salgado Junior et al., 2024; World Economic Forum, 2024).

Applied to Nigeria's EV charging infrastructure choice, the Trilemma reveals that no single charging model simultaneously satisfies all three dimensions under current grid conditions, motivating the proposition of a graduated deployment framework.

2.7. Literature Gap

The existing literature on EV adoption and grid impact in Nigeria has three identifiable gaps that this study addresses. First, no published study applies the EV charging load calculation methodology, incorporating an explicit simultaneous utilisation rate parameter and presented as a formal scenario analysis across multiple fleet size, charger type, and utilisation rate combinations directly to Nigeria's national grid using Nigeria's verified 2024 grid performance data as the baseline denominator (World Bank, 2023b).

The Nairobi and South Africa studies are the closest antecedents, but neither can be applied to Nigeria's grid conditions without transferability. Second, no published study provides a unified comparative assessment of the three principal charging models, private solar home charging, commercial solar charging stations, and grid-based public fast charging against a consistent criterion set simultaneously, using Nigeria-specific parameters.

Third, the existing literature has not produced a grid investment framework that connects the charging load requirements of Nigeria's EV adoption trajectory to the specific energy resource endowments Nigeria possesses 209.26 TCF natural gas reserves, 14,000+ MW undeveloped hydropower potential, and 5.5 kWh/m^2/day solar irradiance with a strategic investment sequencing recommendation grounded in both the demand trajectory and the resource base.

3. Methodology

3.1. Research Design

This study adopts a convergent mixed-methods research design integrating quantitative deterministic scenario modelling with qualitative comparative and policy assessment. The study is an analytical research paper whose central contribution is the application of a structured analytical methodology to existing, verified secondary data. This is a legitimate and well-established category of research design, particularly appropriate when the research question concerns relationships between existing institutional datasets rather than new empirical phenomena (Creswell & Creswell, 2023).

3.2. Phase One: Charging Load Scenario Analysis

The standard EV charging load formula applied in this study is drawn from peer-reviewed EV grid impact literature (Lukuyu et al., 2024; Giliomee et al., 2024) and is stated formally as:

$$P_{\text{grid}}\left(\text{MW}\right) = N_{\text{fleet}} \times U_{\text{rate}} \times P_{\text{charger}} / 1000 \tag{1}$$

where:

P_{grid} = total incremental grid demand imposed by the EV fleet (MW)

N_{fleet} = total registered EV fleet size (number of vehicles)

U_{rate} = simultaneous utilisation rate—the proportion of the total fleet charging at any one moment (dimensionless, expressed as a decimal)

P_{charger} = rated power draw of the charger type used (kW per vehicle)

The simultaneous utilisation rate is the critical parameter that determines whether the calculation is realistic or unrealistic. A U_{rate} of 1.0 (100%) would assume all registered vehicles charge at exactly the same moment, an assumption that is physically implausible and not applied in this study. The U_{rate} values applied in this analysis are drawn from the peer-reviewed EV grid impact literature:

U_{rate} = 0.20 (20%) for Level 2 AC charging: consistent with the residential and workplace overnight charging profile documented by Lukuyu et al. (2024) for the Nairobi market, which exhibits broadly comparable urban commuting patterns to Nigerian cities. At 20%, one in five registered vehicles is charging simultaneously, a conservative peak-period estimate.

U_{rate} = 0.10 (10%) for DC fast charging: consistent with the commercial fast-charging utilisation profile in Giliomee et al. (2024) and standard demand factor calculations for commercial EV charging installations. At 10%, one in ten registered vehicles is simultaneously fast-charging, appropriate for a scenario in which fast charging is used primarily for top-up charging during commercial operation rather than overnight full-cycle charging.

U_{rate} = 0.05 (5%) for DC fast charging as a low-utilisation sensitivity scenario, representing a highly dispersed charging pattern or an early-stage charging network with limited simultaneously available infrastructure.

The transferability of the Nairobi and South Africa utilisation rate data to the Nigerian context is justified as follows: both Kenya and South Africa share broadly comparable urban commuting patterns and paratransit operating structures with Nigeria's major cities; the 10% and 20% rates are at the conservative end of the 8%

- 25% range reported across comparable developing-market urban EV studies; and the nine-scenario analysis in Table 1 of the results section demonstrates that the grid constraint finding is robust across all three utilisation rate assumptions, including the lowest (5%).

The specific threshold at which the grid constraint becomes critical S8, where 1 million vehicles at 10% utilisation on DC fast charging produces 5000 MW represents 100% of Nigeria's available grid output: an outcome that holds regardless of reasonable utilisation rate variation around 10%.

3.3. Phase Two: Three-Model Comparative Assessment

The second phase evaluates three charging infrastructure models, private solar home charging, commercial solar charging stations, and grid-based public fast charging against six criteria: technical feasibility in Nigeria's electricity environment, spatial and capital requirements for meaningful throughput, equity of access across income and tenure categories, maximum realistic charging throughput, resilience under grid failure conditions, and environmental performance. Each criterion is evaluated using quantitative benchmarks where available and qualitative institutional analysis where quantitative benchmarks are insufficient.

3.4. Phase Three: Resource Endowment Mapping

The third phase connects the grid demand findings from Phase One and the charging model assessment from Phase Two to Nigeria's energy resource base, producing the strategic grid investment framework. This phase applies the comparative case analysis technique, drawing on Norway's infrastructure-first EV transition and China's grid-scale energy investment model as benchmarks. The application is conducted with explicit attention to the institutional and resource differences between the source cases and the Nigerian context.

3.5. Assumptions and Limitations

First, the simultaneous utilisation rate assumptions of 20% (Level 2) and 10% (DC fast) are drawn from Kenyan and South African analogues rather than Nigerian primary data, because Nigerian EV adoption data at the required granularity does not yet exist. These rates are conservative relative to developed-market analogues and are tested in sensitivity through the nine-scenario analysis. Second, the grid baseline of approximately 5000 MW is Nigeria's operative available generation, not its nameplate capacity; this choice is methodologically correct for a study of grid adequacy under incremental demand. Third, the three-model comparative assessment treats models as alternatives for analytical clarity; an optimal Nigerian charging infrastructure would incorporate elements of all three in a complementary architecture. Fourth, the resource endowment mapping produces strategic investment directions rather than a fully costed financial model, which is identified as a priority for future research.

4. Data Collection & Validity & Reliability

This study draws on five distinct data streams that includes qualitative expert interviews, quantitative survey reports, policy & Technical assessments, Quantitative User test survey (UTAUT) and institutional data as highlighted in **Table 1** below.

4.1. Data Collection

The remaining data streams are: EV market and policy data drawn from verified institutional and market intelligence sources (IEA, 2024, Accelerating to Zero Coalition 2024, EV World Africa 2025) documenting the global and Nigerian EV adoption trajectory; EV charging equipment specifications (7 kW Level 2, 50 kW DC fast) drawn from internationally published standards and consistent with comparable African grid impact studies; and Nigeria's energy resource endowment data from NUPRC (2024) for natural gas reserves and EIA (2024) for hydropower potential. The decision to use Nigeria's available generation capacity of approximately 5000 MW as the grid baseline rather than nameplate installed capacity of approximately 12,500 MW is a deliberate and consequential methodological choice. A charging load analysis conducted against nameplate capacity would systematically overstate the grid's ability to absorb new EV demand, producing optimistic conclusions that do not reflect the operational reality encountered by vehicle owners and grid operators. Available capacity is the operationally relevant figure for a study of grid adequacy under incremental load.

4.2. Study Validity & Reliability

Internal validity is protected by three features: the explicit parameterisation of the simultaneous utilisation rate in Equation (1), which makes the calculation's assumptions transparent and challengeable rather than implicit; the nine-scenario sensitivity analysis which demonstrates that the grid constraint finding holds across a range of utilisation rate assumptions rather than depending on a single assumed value; and the use of Nigeria's available generation capacity rather than nameplate capacity as the grid baseline, which ensures findings reflect operational rather than theoretical conditions (Creswell & Creswell, 2023).

External validity is explicitly bounded by temporal scope: the analysis is calibrated to Nigeria's grid conditions as of 2024 and early 2025. The specific MW thresholds at which EV charging loads become problematic will shift as grid capacity changes through investment, which is acknowledged as a design feature, the paper establishes the current constraint boundary so that policymakers can track progress against it as investment is made. The simultaneous utilisation rate assumptions from Kenya and South Africa are defended on the grounds of comparability of urban mobility patterns and the conservative end of the observed range, and are tested through the nine-scenario analysis.

Construct validity: incremental grid demand is operationalised as the product of simultaneously charging vehicles and per-vehicle power draw correctly capturing the instantaneous demand increment imposed on the grid. Grid capacity is operationalised as available generation output correctly measuring the system's actual ability to absorb new demand.

Reliability: the deterministic calculation produces identical results for the same inputs regardless of analyst, ensuring perfect replicability. The qualitative model comparison draws on a consistent six-criterion framework applied identically across all three models, reducing but not eliminating evaluative subjectivity, and every rating is anchored to specific quantitative or institutional evidence.

5. Data Analysis & Interpretation

5.1. Charging Load Scenario Analysis with Formal Equations

This section presents the charging load scenario analysis applying Equation (1) (Section 3.2) across nine explicitly parameterised scenarios. The scenarios span four fleet sizes representing the 2025 current fleet, a near-term trajectory, a medium-term trajectory, and a long-term trajectory; two charger types (Level 2 AC and DC fast); and three simultaneous utilisation rates (5%, 10%, and 20%). Table 2 below captures the results.

Table 2. EV charging load scenario analysis—Nigeria, applying Equation (1). Baseline: Nigeria available grid output = 5000 MW (NERC, 2024). U_rate = simultaneous utilisation rate. All figures rounded to the nearest whole number. Critical threshold scenarios (>50% of available grid) are shaded. Sources: Equation 1 parameterisation from Lukuyu et al. (2024); Giliomee et al. (2024); NEC 625.42 (2023); fleet size projections from EV World Africa (2025).

Scenario	Total EV fleet size	Simultaneous utilisation rate	Simultaneously charging vehicles	Charger type	Power per vehicle (kW)	Total incremental grid demand (MW)	As % of Nigeria available grid (5000 MW)
S1	15,000 - 20,000 (2025 fleet)	20%	3000 - 4000	Level 2 AC	7	21 - 28	0.4% - 0.6%
S2	15,000 - 20,000 (2025 fleet)	10%	1500 - 2000	DC Fast	50	75 - 100	1.5% - 2.0%
S3	100,000 (near-term)	20%	20,000	Level 2 AC	7	140	2.8%
S4	100,000 (near-term)	10%	10,000	DC Fast	50	500	10.0%
S5	350,000 (medium-term)	20%	70,000	Level 2 AC	7	490	9.8%
S6	350,000 (medium-term)	10%	35,000	DC Fast	50	1750	35.0%
S7	1,000,000 (long-term)	20%	200,000	Level 2 AC	7	1400	28.0%
S8	1,000,000 (long-term)	10%	100,000	DC Fast	50	5000	100%—critical threshold
S9	1,000,000 (long-term)	5%	50,000	DC Fast	50	2500	50.0%

The results in Table 2 require careful interpretation. At the current fleet size of 15,000 to 20,000 EVs (Scenarios S1 and S2), the incremental grid demand is negligible 0.4% to 2.0% of available grid output, indicating that the current fleet poses no grid constraint challenge.

The grid constraint becomes material at the 100,000-vehicle threshold: Scenario S4 (100,000 vehicles at 10% utilisation on DC fast charging) produces 500 MW of incremental demand, representing 10% of available grid output. At 350,000 vehicles on Level 2 charging at 20% utilisation (Scenario S5), the incremental demand of 490 MW approaches the S4 figure, confirming that Level 2 charging's lower per-vehicle power draw is partially offset by its higher simultaneous utilisation rate.

The most critical threshold is Scenario S8: 1,000,000 vehicles at 10% utilisation on DC fast charging produces 5000 MW of incremental demand equal to Nigeria's entire current available grid output. This is a long-term trajectory scenario, not a near-term risk. However, given that the ZEV Declaration commits Nigeria to 100% ZEV car and van sales by 2040, the long-term fleet trajectory is policy-embedded.

The planning implication is that grid investment must be co-ordinated with EV adoption policy on the same timeline, not treated as a consequent investment to be made after the fleet has grown. Scenario S9 demonstrates that even at the low utilisation rate of 5%, a 1-million-vehicle DC fast-charging fleet still imposes 2500 MW, 50% of available grid output in incremental demand.

To contextualise: the S8 scenario does not imply that Nigeria's grid will collapse when the millionth EV is registered. It implies that if grid investment does not keep pace with EV adoption, the infrastructure will be inadequate to support the fleet that policy is encouraging. The quantitative findings are most valuable as a planning input, establishing the MW requirements at each fleet size milestone rather than as a crisis prediction for a specific date.

5.2. Three-Model Charging Infrastructure Assessment

Table 3 presents the comparative assessment of the three principal charging infrastructure models against six criteria. The assessment demonstrates that each model has binding constraints that prevent it from serving as a standalone mass-market solution under current Nigerian conditions, while each has contexts where it performs well.

Table 3. Three-model charging infrastructure comparative assessment. Sources: Lukuyu et al. (2024); Giliomee et al. (2024); International Energy Agency (2025); NERC (2024); companion studies.

Criterion	Private solar home charging	Commercial solar charging stations	Grid-based public fast charging
Technical feasibility	High—works independently of grid	Moderate—solar generation variability limits throughput	High—if grid is reliable

Continued

Spatial requirements	Requires property ownership and rooftop access—unavailable to renters	Requires significant land area and capital for meaningful throughput	Minimal—leverages existing distribution infrastructure
Equity of access	Low—restricted to property owners with capital	Moderate—accessible at fixed locations	High—if charging network is deployed broadly
Maximum throughput	Limited to one vehicle per household installation	Limited by solar array size and storage capacity	Unlimited—scales with grid capacity
Resilience under grid failure	High—fully independent of grid	High—independent of grid	Low under current grid conditions—improves with grid investment
Environmental performance	Excellent—zero-carbon if solar	Excellent—near-zero carbon	Dependent on grid generation mix—improves as grid decarbonises
Primary binding constraint	Social equity—excludes majority urban population	Capital cost and spatial constraints limit scaling	Grid reliability and capacity—addressable through investment
Recommendation	Support for early adopters with property access	Deploy at strategic high-throughput locations	Target architecture—requires grid investment as precondition

Private solar home charging is technically sound and environmentally excellent but is structurally inequitable available only to property owners with rooftop access and investment capital, a demographic that represents a small minority of Nigeria's urban population. Commercial solar charging stations can serve a wider population but face binding throughput and capital constraints at the scale required for a mass-market EV charging network.

Grid-based public fast charging is more equitable and scalable architecture in principle, but its binding constraint grid reliability and capacity must be addressed through investment before it can function reliably as a mass-market solution. The integrated conclusion is not that one model should replace the others, but that each has a defined role in a complementary deployment architecture sequenced against the grid investment trajectory (Joshi et al., 2025).

5.3. Resource Endowment Mapping

Nigeria's natural gas endowment of 209.26 trillion cubic feet of proven reserves as of January 2024 (NUPRC, 2024) is the most immediately deployable resource for grid expansion, because gas-to-power technology is commercially mature and the reserve endowment is substantial. Nigeria's gas-to-power conversion rate is currently inefficient due to pipeline security, supply contracts, and payment chain failures rather than reserve scarcity.

Hydropower potential of over 14,000 MW, of which approximately 85% remains undeveloped (EIA, 2024), represents the largest renewable baseload opportunity but requires 8 - 15 year development timelines. Large-scale grid-connected solar, deployable in 2 to 4 years at a levelised cost of USD 0.044/kWh (IRENA, 2024), represents the fastest pathway to near-term generation capacity expansion.

The strategic sequencing conclusion is: near-term (0 - 5 years) utility-scale solar and gas-to-power pipeline rehabilitation; medium-term (5 - 15 years) accelerated hydropower development; throughout all phases, transmission network rehabilitation, without which generation expansion cannot reach end users.

5.4. Integrated Interpretation

The charging load scenario analysis, the three-model assessment, and the resource endowment mapping converge on the same conclusion: Nigeria's EV transition requires explicit policy co-ordination between EV adoption incentives and grid investment planning, implemented through a joint EV-Grid planning mechanism that uses fleet size milestones from **Table 2** as grid investment triggers.

The analysis does not support the conclusion that Nigeria must resolve its entire electricity access deficit before EV adoption can begin, the current fleet of 15,000 to 20,000 vehicles imposes negligible grid demand and can be accommodated without investment. What the analysis supports is that policy cannot continue to accelerate EV adoption without a parallel, quantified grid investment programme that keeps the available generation capacity above the critical thresholds identified at each fleet size milestone in **Table 2**.

5.5. Discussions & Findings

The charging load scenario analysis presented in this paper advances the existing literature in a specific and bounded way. The Nairobi and South African studies the closest antecedents demonstrate through simulation that EV adoption imposes significant loads on constrained African electricity systems, but neither applies the analysis to Nigeria's specific grid baseline, fleet size trajectory, or the simultaneous utilisation rate parameterisation that this paper makes explicit. The nine-scenario table in Section 9.1 is the first published analysis to apply the standard charging load formula across a range of utilisation rates to Nigeria's verified grid performance data, producing threshold estimates that can be used as planning inputs.

The Nigerian expert interview evidence from Farinloye et al. (2024) 31 experts and the UTAUT-based Nigerian survey evidence provide Nigerian-grounded confirmation that the grid infrastructure constraint is the primary adoption barrier identified by Nigerian practitioners and consumers, not merely an analytical projection from international data. This convergence between the quantitative scenario analysis and the Nigerian expert and survey evidence is the paper's focal methodological feature: two independent evidence streams, one quantitative, one qualitative point to the same constraint from different methodological directions.

The three-model assessment and resource endowment mapping translate the analytical finding into a policy framework. The framework is not novel in its general direction, the need for grid investment alongside EV adoption has been stated in various forms by multiple commentators. What this paper adds is the quantification: the specific MW thresholds at each fleet size milestone that grid investment must keep the available generation above, the specific resource endowments Nigeria possesses that can supply that generation, and the specific timeline sequencing across solar, gas, and hydropower development pathways.

The most significant is the absence of Nigerian primary data on simultaneous utilisation rates and daily driving distances, which requires the use of comparable African analogues with explicit transferability justification.

6. Summary & Recommendations

This paper has examined the energy infrastructure dimensions of Nigeria's electric vehicle transition through three analytical phases: a nine-scenario charging load analysis applying a formally stated simultaneous utilisation rate parameter, a comparative three-model assessment, and a resource endowment mapping.

The analysis draws on Nigerian expert interview evidence from 31 practitioners (Farinloye et al., 2024), Nigerian-specific survey evidence confirming grid reliability as the primary adoption barrier, Nigerian institutional grid performance data from NERC (2024), and international comparative data from Norway and China where Nigerian primary data is not available.

The study finds that Nigeria's current EV fleet of 15,000 to 20,000 vehicles imposes negligible incremental grid demand (Scenarios S1 and S2: 0.4% - 2.0% of available grid output), and that the grid constraint becomes material at the 100,000-vehicle threshold (Scenario S4: 10% of available grid output at 10% DC fast charging utilisation). At the long-term ZEV Declaration trajectory of full fleet electrification, the incremental charging demand approaches or exceeds available grid capacity under conservative utilisation assumptions (Scenarios S8 and S9), confirming that grid investment must be co-ordinated with EV adoption policy on the same planning timeline. These findings are consistent with, and grounded in, the Nigerian expert evidence which identifies grid infrastructure as the primary adoption barrier.

The study makes four specific contributions to knowledge: 1) it is the first to apply the standard EV charging load formula with an explicit, parameterised simultaneous utilisation rate to Nigeria's verified 2024 grid performance data across a nine-scenario matrix, producing threshold estimates usable as planning inputs; 2) it is the first to ground the Nigerian grid constraint finding in Nigerian expert interview and survey evidence alongside institutional data, establishing that the constraint is confirmed from the demand side as well as the supply side; 3) it provides a comparative three-model charging infrastructure assessment calibrated to Nigerian conditions; and 4) it maps the charging load requirements of Nigeria's EV adoption trajectory against Nigeria's specific energy resource endowments with a strategic investment sequencing recommendation.

Policy recommendations: 1) A joint EV-Grid Task Force at cabinet level should be established, mandated to align EV adoption trajectory projections with grid investment milestones using the fleet size thresholds in **Table 2** as planning triggers. 2) NERC should incorporate EV charging load projections into grid capacity planning as a mandatory input, publishing annual EV-adjusted demand forecasts. 3) Nigeria's gas-to-power pipeline rehabilitation should be treated as the most urgent near-term generation investment, addressing the institutional and contractual failures that prevent existing reserves from reaching generating capacity. 4) A nationally co-ordinated utility-scale solar programme should be established as the fastest near-term renewable generation expansion pathway. 5) Transmission network rehabilitation should be treated as a co-equal investment priority with generation expansion, given the 8100 MW wheeling constraint documented by Ukpe (2024). 6) All new commercial developments should incorporate EV charging infrastructure as a planning permission condition, sized for grid-connected fast charging and activated progressively against grid reliability milestones.

Directions for future research: 1) Nigerian primary data collection on EV charging behaviour—simultaneous utilisation rates, daily driving distances, and charging session duration—to replace the Kenyan and South African analogues used in this study; 2) A full techno-economic analysis of the gas-to-power, utility-scale solar, and hydropower investment pathways with capital cost, financing structure, and levelised cost of electricity quantification; 3) A geospatial analysis of optimal public fast-charging network locations using Nigerian traffic flow data; 4) A grid impact simulation for Nigeria using the Monte Carlo charging load methodology (comparable to the approach of Lukuyu et al., 2024) for Nairobi with Nigerian-specific input parameters once primary behavioural data are available.

Author Contributions

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Conflicts of Interest

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

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