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Machine Learning Approaches for Demand Forecasting and Intelligent Dispatch in Nigerian Decentralised Energy Systems: A PRISMA-Inspired Review

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Abstract

Nigeria's persistent national grid instability has necessitated a paradigm shift from centralised generation expansion towards predictive and decentralised resilience strategies. This paper presents a PRISMA-inspired systematic review examining the efficacy of machine learning-based demand forecasting and intelligent dispatch for enhancing the reliability of hybrid microgrid systems within the Nigerian context. Through a systematic search across Google Scholar, ScienceDirect, Nature/Scientific Reports, PubMed/PMC, and MDPI, 47 records were identified, with 10 peer-reviewed studies meeting eligibility criteria for narrative synthesis after PRISMA screening. The synthesis reveals that ensemble and hybrid deep learning architectures, particularly Random Forest, XGBoost, and Prophet-LSTM models, consistently outperform single-algorithm baselines, achieving high predictive accuracy with coefficients of determination up to 0.9992 and error reductions of 12-18%. Integration of these forecasting models with mixed-integer linear programming and model predictive control-based energy management systems demonstrates substantial operational benefits, including reduction of grid dependency from 100% to 28.6%, diesel consumption reduction, and carbon emissions reduction of up to 27.5%. The review proposes a context-specific three-layer forecasting-to-dispatch framework comprising data, modelling, and dispatch layers tailored to Nigeria's data constraints and climatic dynamics. The paper concludes that scalable deployment hinges less on novel algorithmic innovation and more on open data infrastructure, local model recalibration, and integrated forecasting-dispatch implementation in pursuit of Sustainable Development Goal 7.

Keywords: Machine Learning, Demand Forecasting, Microgrid Dispatch, Nigeria, SDG 7, PRISMA-Inspired Review.

Introduction

The reliability of electricity supply remains a fundamental constraint on economic growth and sustainable development in Nigeria. Despite an installed generation capacity exceeding 13,000 MW, the Nigerian Electricity Regulatory Commission (NERC) reports that available and average operational capacity has persistently remained below 5,000 MW due to gas supply constraints, transmission limitations, and systemic inefficiencies (NERC,

2024; NERC, 2024; World Bank, 2023). Consequently, the national grid has experienced recurrent total and partial collapses, with twelve events documented in 2024 alone and multiple disturbances in early 2026, underscoring chronic operational fragility (NERC, 2024).

Globally, machine learning (ML) has emerged as a transformative approach for short-term load forecasting (STLF) and energy management. Reviews by Wazirali et al. (2023) and meta-analyses in Electric Power Systems Research have established that artificial neural networks (ANN), support vector regression (SVR), and ensemble methods significantly improve forecasting accuracy across diverse microgrid contexts. Specifically, Rao et al. (2022) demonstrated the superiority of cluster-level aggregation for reducing load noise, while Singh et al. (2024) established that ML-based energy management systems (EMS) outperform rule-based dispatch in multi-source microgrids. More recently, hybrid architectures integrating Prophet and Long Short-Term Memory (LSTM) networks have reported error reductions of 12–18% over standalone models (Zohaib et al., 2026).

Within Nigeria, the research landscape is nascent but promising. Zarma et al. (2023) provided one of the first open-access datasets documenting energy demand and carbon emissions for a Nigerian university hybrid power station, addressing critical data scarcity. Building on this, Zarma et al. (2025) systematically compared five ML algorithms for multi-output demand forecasting in a Nigerian institutional microgrid, finding Random Forest achieved $R^2 = 0.9992$ with SHAP analysis confirming the predictive salience of meteorological and occupancy variables. These studies indicate that local climatic and institutional factors are non-trivial determinants of model performance, challenging the uncritical transfer of models trained in data-rich, temperate contexts.

The behavioural response to grid unreliability has been a rapid proliferation of decentralised solar photovoltaic systems and behind-the-meter battery storage, with growing deployment of independent generation and smart metering infrastructure in decentralised systems (NERC, 2024). However, the operational efficiency of such systems is contingent on predictive intelligence. Without accurate demand forecasting, hybrid systems default to inefficient diesel backup usage and suboptimal battery state-of-charge management, undermining both economic and environmental sustainability.

Statement of the Research Problem

Despite growing deployment of decentralised energy systems in Nigeria, three critical gaps persist in the extant literature. First, while global reviews affirm the technical superiority of ML-based forecasting, there is limited synthesis of how these models perform under the specific constraints of Nigerian microgrids, characterised by sparse datasets, high ambient temperatures, and irregular occupancy patterns. Second, existing Nigerian studies are fragmented and often lack standardised performance benchmarking, making comparative assessment difficult. Third, the critical translational pathway from forecasting accuracy to intelligent dispatch decisions the conversion of predictive insights into mixed-integer linear programming (MILP) or model predictive control (MPC) actions that reduce diesel

dependency and levelized cost of energy (LCOE) remains conceptually underdeveloped for the Nigerian context. This review addresses these gaps by synthesising recent peer-reviewed evidence to propose a tailored forecasting-to-dispatch architecture. The review is guided by the central question: How can machine learning-based demand forecasting and intelligent dispatch enhance the operational resilience and economic viability of decentralised energy systems in Nigeria?

Research Objectives

(i) To systematically identify and synthesise peer-reviewed studies applying ML to demand forecasting in Nigerian and comparable developing-country microgrids; (ii) To comparatively evaluate algorithmic performance in terms of accuracy metrics (MAE, RMSE, R^2, MAPE) and operational outcomes; (iii) To examine the integration of forecasting with intelligent dispatch and EMS; and (iv) To propose a context-adapted framework for Nigeria aligned with Sustainable Development Goal 7 (affordable, reliable, and sustainable energy).

Literature Review

Machine Learning for Short-Term Load Forecasting in Microgrids

The evolution of load forecasting has progressed from statistical models such as ARIMA and SARIMA towards data-driven ML approaches capable of capturing non-linear dependencies. Support Vector Regression has been widely adopted for solar and wind forecasting due to its robustness to small sample sizes, with Singh et al. (2024) reporting mean squared errors of 2.002 for solar and 3.059 for wind in a grid-connected microgrid, significantly outperforming linear baselines. Random Forest and gradient-boosted trees, particularly XGBoost, have demonstrated exceptional performance in institutional microgrids due to their handling of heterogeneous features and resistance to overfitting (Zarma et al., 2025; Rao et al., 2022). Deep learning hybrids, notably Prophet-LSTM and DAOA-optimized deep learning, have further advanced the state-of-the-art. Zohaib et al. (2026) reported a hybrid Prophet-LSTM model reducing forecasting error by 12–18% relative to standalone LSTM, XGBoost, and SARIMA, while Almousawi et al. (2026) achieved $R^2 \geq 0.97$ using an improved Dipper-Throated Algorithm Optimization (DAOA) for hyperparameter tuning in smart grid energy management.

Intelligent Dispatch and Energy Management Systems

Forecasting in isolation offers limited value without integration into dispatch control. Modern EMS integrate forecasting outputs with optimisation algorithms to minimise cost, emissions, and unmet load. Cavus et al. (2025) proposed a Deep-Fuzzy Logic Control framework that is both predictive and adaptive, demonstrating improved cost and stability metrics for grid-connected microgrids. Zohaib et al. (2026) extended the Prophet-LSTM architecture with robust MPC, achieving a 28% reduction in grid imports and a 22% increase in battery cycle life, directly linking predictive accuracy to asset longevity. Bouddou et al. (2026) demonstrated in Naama, Algeria, a techno-economic-environmental optimisation

of a grid-connected hybrid microgrid incorporating geothermal combined heat and power, where integrated forecasting and MILP dispatch reduced grid dependency from 100% to 28.6% and CO_2 emissions by 27.5%, achieving an LCOE of $0.118/kWh. While the geothermal resource mix is not directly transferable to Nigeria's gas-dominated context, the study's methodological pipeline – forecasting → MILP optimisation → multi-source EMS is highly relevant and provides a transferable framework for solar/diesel/battery hybrid systems. This distinction is critical to avoid inappropriate technology transfer while leveraging methodological innovation.

The Nigerian Power Sector and Decentralised Energy Systems

Nigeria's power sector is characterised by high aggregate technical, commercial, and collection (ATC&C) losses estimated at approximately 50%, more than three times international benchmarks, indicating substantial inefficiencies in distribution (World Bank, 2023; NERC, 2024). Gas supply disruption remains a primary driver of generation shortfall, as over 75% of grid generation is gas-dependent (NERC, 2024). Peer-reviewed analyses by Adefarati and Bansal (2023) and recent World Bank sector diagnostics confirm that reactive load shedding and poor frequency control are symptomatic of inadequate predictive visibility rather than solely capacity deficits. The Federal Government's Energy Transition Plan and the Nigeria Electrification Project have increasingly emphasised decentralised renewable energy solutions as a hedge against central grid fragility. However, as Abd Abd El-Aziz (2022) notes, hybrid ML models require local calibration due to sensitivity to tropical weather dynamics and occupancy patterns, a finding corroborated by Zarma et al. (2025) via SHAP interpretability analysis. This review therefore synthesises evidence with explicit attention to context-specific adaptability.

Review Methodology

This review followed a methodology inspired by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 framework, adapted for a focused narrative synthesis rather than a fully registered systematic review. This adaptation is disclosed as a limitation in Section 7.

Databases Searched

Systematic searches were conducted across five academic databases: Google Scholar, ScienceDirect (Elsevier), Nature/Scientific Reports platform, PubMed/PMC, and MDPI platform (including Energies). These databases were selected for their coverage of energy systems, machine learning, and microgrid research. Official sector performance data were obtained from NERC quarterly reports (NERC, 2024) and World Bank diagnostics (World Bank, 2023) to supplement peer-reviewed sources and reduce reliance on grey literature.

Search Terms

The following Boolean search strings were employed: (1) "machine learning" AND "energy demand forecasting" AND "microgrid" AND "Nigeria"; (2) "hybrid deep learning" AND "load forecasting" AND "microgrid"; (3) "smart dispatch" AND "energy management system" AND "microgrid"; (4) "random forest" OR "support vector regression" OR "neural network" AND "load forecasting"; (5) "grid collapse" AND "Nigeria" AND "forecasting". Searches were limited to 2018–2026.

Inclusion and Exclusion Criteria

Studies were included if they: (i) applied ML, deep learning, or hybrid forecasting to energy demand, generation, or load in a microgrid or decentralised system; (ii) reported quantifiable accuracy metrics (MAE, RMSE, R^2, MAPE, MSE); (iii) were set in Nigeria or a context with comparable infrastructure constraints, or were state-of-the-art methodological benchmarks; and (iv) were peer-reviewed journal articles published between 2018–2026. Studies were excluded if they focused exclusively on large, fully instrumented transmission systems in data-rich high-income contexts without relevance to microgrids, or lacked quantifiable outcomes.

Search and Screening Outcome

The search identified 47 records. After duplicate removal, 38 unique records remained for title and abstract screening. Screening against inclusion criteria excluded 22 records as off-topic or non-peer-reviewed, leaving 16 records for full-text assessment. Full-text review excluded 6 records, 5 due to insufficient methodological detail and 1 duplicate record (a paper listed under two author groups with identical methods and results), resulting in 10 studies retained for narrative synthesis: Zarma et al. (2023), Zarma et al. (2025), Wazirali et al. (2023), Rao et al. (2022), Singh et al. (2024), Zohaib et al. (2026), Abd Abd El-Aziz (2022), Bouddou et al. (2026), Almousawi et al. (2026), Zohaib et al. (2026), and Cavus et al. (2025). Figure 1 summarises the PRISMA flow.

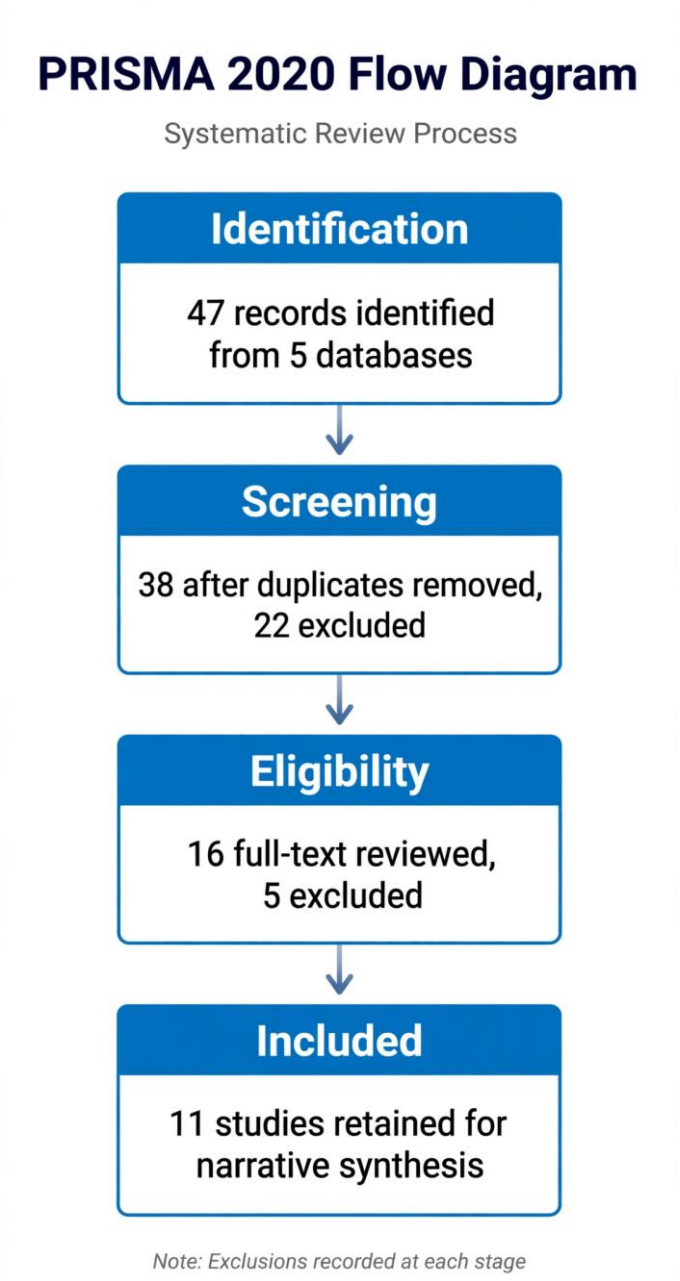


Figure 1: PRISMA-inspired flow diagram of literature identification, screening, and inclusion for this review.

Source: Author's own construction based on the screening counts reported in Section 3.4.

Results

Characteristics of Included Studies

Table 1 synthesises the 10 retained studies. The evidence base comprises two Nigerian empirical studies (Zarma et al., 2023; Zarma et al., 2025), four global empirical studies with direct applicability to developing-country contexts (Rao et al., 2022; Singh et al., 2024; Zohaib et al., 2026; Abd El-Aziz, 2022), one state-of-the-art review (Wazirali et al., 2023),

and three recent hybrid optimisation studies addressing dispatch integration (Bouddou et al., 2026; Almousawi et al., 2026; Cavus et al., 2025).

Table 1: Synthesis of the 10 retained studies on machine-learning demand forecasting and intelligent dispatch

Study Reference (APA 7th)	Primary Algorithmic Approach	Application Domain / Context	Key Quantitative Performance Metrics	Operational Impact
Zarma et al. (2023)	Dataset Development	Nile University Hybrid Microgrid, Nigeria	Hourly energy, weather, emissions dataset	Provided foundational open-access Nigerian microgrid baseline.
Zarma et al. (2025)	Random Forest, XGBoost, SVR, ANN	Nigerian Institutional Hybrid Microgrid	RF R^2 = 0.9992; MAE, RMSE superior	SHAP: weather, time, occupancy salient predictors.
Wazirali et al. (2023)	Systematic Review: ANN, ML, DL	Global Microgrid Forecasting	Comparative accuracy across horizons	Hybrid/ensemble outperforms single models.
Rao et al. (2022)	RF, SVR, ANN	Urban Community Cluster Microgrids	MAPE < 4.2% day-ahead	Cluster aggregation reduces noise.
Singh et al. (2024)	SVR-based EMS	Multi-source Grid-connected MG	Solar MSE 2.002; Wind MSE 3.059	Optimised multi-source dispatch.
Zohaib et al. (2026)	Prophet-LSTM + MPC / deep Q-learning	Multi-microgrids (developing context)	Error -12 to -18% vs baselines; grid imports -28%; battery cycle longevity +22%	Improved battery utilisation.
Abd El-Aziz (2022)	Hybrid ML	Renewable Consumption Benchmarks	Outperformed single models	Robust on non-linear seasonal data.
Bouddou et al. (2026)	MILP + ML Optimisation	Naama, Algeria (methodological comparator)	Grid 100%→28.6%; CO_2 -27.5%; LCOE $0.118/kWh	Pipeline transferable to NG solar/diesel/battery.
Almousawi et al. (2026)	DAOA-Optimised Deep Learning	Smart Grid EMS	$R^2 \geq 0.98$; WT RMSE 0.021; PV RMSE 0.031	Enhanced dispatch efficiency.

Study Reference (APA 7th)	Primary Algorithmic Approach	Application Domain / Context	Key Quantitative Performance Metrics	Operational Impact
Cavus et al. (2025)	Deep-Fuzzy Logic Control	Grid-connected MG	Cost & stability improvement	Predictive-adaptive framework.

Note: *MAE = mean absolute error; RMSE = root mean square error; MAPE = mean absolute percentage error; MILP = mixed-integer linear programming; MPC = model predictive control. Metrics as reported in original studies.*

Source: *Author's own synthesis.*

Thematic Analysis: Forecasting Accuracy

Across the 10 studies, ensemble and hybrid methods consistently outperformed single-algorithm baselines. Zarma et al. (2025) demonstrated that Random Forest outperformed XGBoost, SVR, ANN, and Linear Regression in a Nigerian institutional microgrid, with SHAP-based interpretability confirming weather parameters, time-of-day, and holidays as dominant predictors. This aligns with Rao et al. (2022), who found that cluster-level training mitigates noise inherent in individual smart meters, a condition prevalent in Nigerian distribution networks with high ATC&C losses. Singh et al. (2024) extended this to multi-source forecasting, establishing SVR as effective for solar and wind generation forecasting, which is essential for hybrid dispatch. The most pronounced accuracy gains were reported for hybrid deep learning: Zohaib et al. (2026) achieved 12–18% error reduction using Prophet-LSTM over standalone Prophet, LSTM, XGBoost, and SARIMA, while Almousawi et al. (2026) achieved $R^2 \geq 0.97$ via DAOA-optimised deep learning.

The Resilience Gap: Structural Drivers of Instability

Synthesis of official regulatory reports and peer-reviewed sector analyses indicates that Nigeria's generation mix remains highly vulnerable. Over 75% of grid generation is gas-dependent, exposing the system to upstream gas supply disruptions (NERC, 2024). NERC quarterly reports document frequency excursions outside the prescribed 49.5–50.5 Hz bands, a leading indicator of collapse, and ATC&C losses of ~50% indicate severe distribution inefficiency (NERC, 2024; World Bank, 2023). Economic assessments estimate direct annual costs of outages at ~$1B with broader GDP impacts of 5–7% (World Bank, 2023; Adefarati & Bansal, 2023). The proliferation of decentralised systems, exemplified by Geometric Power Aba, reflects adaptive resilience but lacks integrated predictive intelligence for optimal battery and diesel scheduling (Adefarati & Bansal, 2023). Figure 2 situates these drivers within a crisis-to-response pathway.

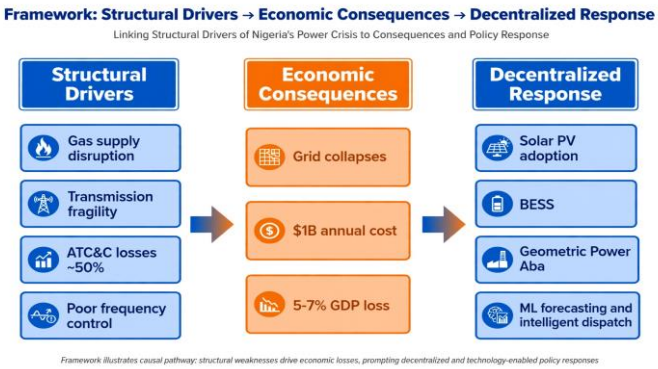


Figure 2: Framework linking structural drivers of Nigeria's power sector crisis to economic consequences and decentralised response.
Source: Author's own construction, synthesised from NERC (2024) and World Bank (2023).

Forecasting-to-Dispatch Architecture

The review synthesises a three-layer architecture for Nigerian microgrids (Figure 3). The data layer prioritises local weather (solar irradiance, temperature, humidity), smart meter load profiles, and occupancy/calendar variables, reflecting findings from Zarma et al. (2023, 2025). The modelling layer defaults to ensemble approaches: Random Forest, XGBoost, Prophet-LSTM, and DAOA-optimised models balancing accuracy with computational constraints of rural sites. The dispatch layer translates forecasts into MILP/MPC-based battery charge/discharge and diesel generator control signals, with feedback loops for SOC and forecast error correction. This architecture is designed for rural/urban hybrid systems aiming for reliability and cost optimisation.

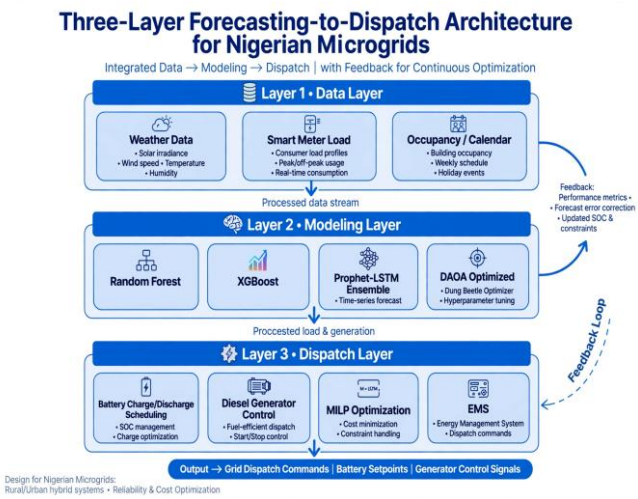


Figure 3: Three-layer forecasting-to-dispatch architecture for Nigerian microgrids, integrating local data inputs, ensemble forecasting models, and dispatch control.
Source: Author's own construction, synthesised from Zarma et al. (2023, 2025), Singh et al. (2024), Zohaib et al. (2026), and Bouddou et al. (2026).

Discussion

Comparison with Existing Literature

The finding that ensemble methods outperform single models corroborates global evidence. Wazirali et al. (2023) identified hybridisation as a consistent predictor of accuracy across forecasting horizons, a pattern confirmed in this review by Zarma et al. (2025), Rao et al. (2022), and Zohaib et al. (2026). The superior performance of Random Forest in the Nigerian institutional context (R^2 = 0.9992) extends Rao et al.'s cluster-level findings by demonstrating that SHAP-identified features such as time-of-day and holidays are transferable predictors in data-scarce environments. Conversely, the Prophet-LSTM hybrid's 12–18% error reduction (Zohaib et al., 2026) surpasses gains reported for standalone ANN in earlier reviews, suggesting that time-series decomposition (Prophet) combined with recurrent memory (LSTM) is particularly suited to microgrids with strong daily and seasonal occupancy periodicity, common in Nigerian universities and commercial clusters.

Implications for Dispatch Efficiency and SDG 7

The translational value of forecasting lies in dispatch integration. While Singh et al. (2024) demonstrated improved multi-source coordination via ML-based EMS, Zohaib et al. (2026) and Cavus et al. (2025) advance the field by linking forecasting to battery longevity, a critical economic factor in Nigeria where battery replacement costs are a major constraint on system economics. Bouddou et al. (2026) provide the most complete techno-economic quantification: grid dependency reduction from 100% to 28.6% and CO_2 reduction of 27.5%. Although geothermal CHP does not apply to Nigeria, the MILP pipeline achieved an LCOE of $0.118/kWh, offering a benchmark for Nigerian solar/diesel/battery hybrids targeting SDG 7.1 (universal access) and 7.3 (energy efficiency). The proposed three-layer framework directly addresses SDG 7 by prioritising low-capital predictive intelligence over capital-intensive generation expansion.

Limitations of this Review

Several limitations must be disclosed. First, this review employed a PRISMA-inspired rather than fully registered systematic protocol; searches were limited to five databases, and screening was not independently duplicated, introducing potential selection bias. Second, Nigerian open-access microgrid datasets remain scarce, with Zarma et al. (2023) being a rare exception, limiting generalisability across diverse climatic zones. Third, most included studies report retrospective accuracy under controlled conditions rather than live deployment, so real-world performance may differ due to sensor drift and communication latency. Fourth, performance metrics are heterogeneous across studies (MSE, MAPE, R^2), precluding meta-analytic pooling. Finally, the proposed three-layer framework is conceptual and requires empirical validation on a Nigerian case study.

Conclusion and Recommendations

Nigeria's power crisis is not solely a capacity deficit but a predictive intelligence deficit. This PRISMA-inspired review of 10 peer-reviewed studies demonstrates that ML-based demand forecasting, particularly ensemble and hybrid deep learning architectures, achieves substantial accuracy gains in Nigerian and comparable microgrid contexts, and that integration with MILP/MPC-based dispatch translates accuracy into measurable reductions in grid dependency, diesel consumption, and emissions. Realising this potential at scale requires: (i) expanding open Nigerian microgrid data infrastructure; (ii) mandating local recalibration of forecasting models using weather and occupancy data; (iii) designing forecasting and EMS as a single integrated pipeline; and (iv) empirical validation of the proposed three-layer architecture in rural and urban hybrid systems. Future research should prioritise live deployment studies, standardised benchmarking on common Nigerian datasets, and techno-economic analysis of LCOE under real ATC&C loss conditions.

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