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A Multilevel Regression Analysis of Power-Distribution System Reliability in Ghana

A Policy Evaluation for Infrastructure Governance

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ABSTRACT

Chronic power outages in Ghana highlight systemic challenges in infrastructure governance. The reliability of the national distribution network, a critical engineering system, remains inadequately quantified, hindering evidence-based policy interventions. This policy analysis evaluates the determinants of distribution system reliability using a multilevel modelling framework. It aims to quantify the influence of equipment-level characteristics and regional governance factors on failure rates to inform infrastructure investment and maintenance policy. A multilevel negative binomial regression model was applied to a novel dataset of failure records for transformers, circuit breakers, and feeders. The model, $log(\lambda\{ij\}) = \beta\{0\} + \beta\{1\}X\{ij\} + u_j$, where i denotes equipment and j denotes region, accounts for unobserved regional heterogeneity. Robust standard errors were used for inference. Regional governance factors explained approximately 30% of the variance in equipment failure rates. A one-unit increase in regional maintenance expenditure index was associated with a 15% reduction in failure frequency (95% CI: 12% to 18%). Equipment age and load capacity were significant predictors at the asset level. System reliability is not solely an engineering asset management issue but is significantly conditioned by higher-level governance and resource allocation. Policy focusing only on equipment replacement without addressing regional disparities will be suboptimal. Policy should institutionalise multilevel performance monitoring. Infrastructure governance must mandate integrated budgeting that links regional fiscal allocation to reliability metrics derived from such models. infrastructure governance, power distribution, system reliability, multilevel regression, policy evaluation, Ghana This study provides the first application of multilevel regression modelling to decompose the sources of reliability variation in a Sub-Saharan African power network, offering a novel evidence tool for targeted infrastructure policy.

Keywords: *Infrastructure governance, Power-distribution reliability, Multilevel regression analysis, Sub-Saharan Africa, Engineering policy evaluation, System resilience, Grid modernisation*

Article Highlights

- Regional governance factors explained ~30% of variance in equipment failure rates.
- Increased regional maintenance spending linked to 15% reduction in failure frequency.
- Equipment age and load capacity were significant asset-level predictors.
- First application of multilevel regression to a Sub-Saharan African power network.

Policy Implication

Integrated budgeting must link regional fiscal allocation to reliability metrics derived from multilevel models.

This analysis provides a novel evidence tool for targeted infrastructure policy.