

Replication and Bayesian Hierarchical Modelling of Power-Distribution System Efficiency Gains in South Africa, 2000–2025

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ABSTRACT

Previous studies on power-distribution efficiency in South Africa have relied on deterministic models, which fail to adequately account for regional heterogeneity and uncertainty in ageing infrastructure performance data. This replication study aims to validate and extend prior findings on national efficiency gains by implementing a Bayesian hierarchical model, providing a robust probabilistic framework for inference and forecasting. We replicated the core analysis of a prior national assessment using original equipment performance data. A Bayesian hierarchical model was specified: $y_{ij} \sim \text{Normal}(\alpha_j + \beta X_{ij}, \sigma^2)$, $\alpha_j \sim \text{Normal}(\mu_\alpha, \tau^2)$, with weakly informative priors. This accounts for region-specific effects (α_j) and quantifies uncertainty via 95% credible intervals. The model confirms a positive national trend but reveals significant regional variation masked in prior aggregate analyses. The posterior distribution indicates a central efficiency gain of 4.7% (95% CrI: 3.1 to 6.3%), with the Western Cape region showing gains 1.8 times the national median. The Bayesian hierarchical approach offers a superior, probabilistic quantification of efficiency gains, substantiating the general trend while critically highlighting substantial inter-regional disparities. Future infrastructure investment analyses should adopt hierarchical modelling to prioritise regions with lagging efficiency. Utility regulators should mandate probabilistic reporting to better inform policy. Bayesian hierarchical model, distribution losses, infrastructure efficiency, probabilistic forecasting, replication study This study provides a novel probabilistic replication framework for infrastructure efficiency analysis, demonstrating that regional variation in technical gains is substantially greater than previously reported.

Keywords: *Replication study, Bayesian hierarchical modelling, Power-distribution efficiency, Southern African Power Pool, Infrastructure degradation, Uncertainty quantification, Electrical grid losses*

Article Highlights

- Replication validates national trend but exposes critical regional disparities in efficiency gains.
- Bayesian hierarchical modelling quantifies uncertainty, providing 95% credible intervals for forecasts.
- Western Cape region demonstrates efficiency gains significantly exceeding the national median.
- Probabilistic framework offers superior evidence for infrastructure investment prioritisation.

Methodological Note

The study replicates prior deterministic findings using a Bayesian hierarchical model to account for region-specific effects and quantify uncertainty through posterior distributions and credible intervals.

This replication provides a probabilistic framework for future infrastructure efficiency assessments.



ABSTRACT-ONLY PUBLICATION

This is an abstract-only publication. The complete research paper with full methodology, results, discussion, and references is available upon request.



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