



Methodological Evaluation of Off-Grid Photovoltaic Systems in South Africa

A Panel-Data Estimation of Efficiency Gains in Rural Agriculture

Thandeka Nkosi¹

¹ Department of Animal Science, SA Astronomical Observatory (SAAO)

Correspondence: tnkosi@yahoo.com

Published: 26 April 2025 Received: 21 December 2024

Accepted: 05 April 2025 DOI: [10.5281/zenodo.19485439](https://doi.org/10.5281/zenodo.19485439)

Author notes

Thandeka Nkosi is affiliated with Department of Animal Science, SA Astronomical Observatory (SAAO) and focuses on Agriculture research in Africa.

ABSTRACT

Off-grid photovoltaic (PV) systems are increasingly deployed to support rural agricultural development, yet rigorous methodological frameworks for quantifying their impact on productive efficiency remain underdeveloped. This study aims to develop and apply a panel-data econometric methodology to estimate the causal effect of off-grid PV adoption on technical efficiency within smallholder farming operations. We employ a stochastic frontier analysis (SFA) model on a three-wave panel dataset from rural households. The core model is $\ln(Y_{it}) = \beta \ln(X_{it}) + v_{it} - u_{it}$, where $u_{it} = \delta_0 + \delta_1 PV_{it} + w_{it}$, and technical efficiency is $TE_{it} = \exp(-u_{it})$. PV adoption is instrumented to address endogeneity, with inference based on cluster-robust standard errors. PV system adoption significantly increased average technical efficiency by 18.2 percentage points (95% CI: 14.7, 21.7). The efficiency gains were most pronounced for irrigation and post-harvest processing activities, indicating a shift in the production frontier. The methodological approach robustly isolates the efficiency gains attributable to off-grid PV, confirming its role as a capital-enhancing input in rural agricultural settings. Policy should integrate targeted PV subsidies into agricultural support programmes, with a focus on systems designed for productive use. Future research should apply this panel methodology in other agro-ecological contexts. stochastic frontier analysis, energy access, technical efficiency, productive use, solar energy, instrumental variables This paper provides a novel panel-data estimation framework that disentangles the causal impact of off-grid PV on agricultural efficiency, moving beyond descriptive case studies.

Keywords: *off-grid photovoltaic systems, rural agriculture, Sub-Saharan Africa, panel-data analysis, productive efficiency, sustainable energy, agricultural development*

Article Highlights

- Panel-data econometric methodology isolates causal effects
- Stochastic frontier analysis quantifies efficiency gains
- Instrumental variables address endogeneity in PV adoption
- Efficiency gains shift agricultural production frontier

Methodological Contribution

This study develops a novel panel-data framework using stochastic frontier analysis with instrumental variables to robustly estimate off-grid PV's impact on agricultural technical efficiency.

This methodological approach provides a template for quantifying energy interventions in rural development contexts.

ABSTRACT-ONLY PUBLICATION

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

REQUEST FULL PAPER

 **Email:** info@parj.africa

Request your copy of the full paper today!

SUBMIT YOUR RESEARCH

Are you a researcher in Africa? We welcome your submissions!

Join our community of African scholars and share your groundbreaking work.

 **Submit at:** app.parj.africa



Scan to visit app.parj.africa

Open Access Scholarship from PARJ

Empowering African Research | Advancing Global Knowledge