International Journal of Economics and Development Policy (IJEDP)
Vol. 8 No. 1, June, 2025
Print - ISSN: 2651-5644
Online - ISSN: 2811-2288

Solar-Powered Irrigation and Cost Efficiency: Evidence Derived from Rice and Vegetable Farmers in Sokoto State - Nigeria

[1] Musa Shehu Anfani, [2] Shuaibu Musa Galli, & [3] Yakubu Ibrahim

[1] Department of Economics, Ibrahim Badamasi Babangida University, Lapai – Nigeria
[2] Department of Economics, Yobe State University, Damaturu – Nigeria
[3] Department of Forestry and wildlife Management, Federal Univerty, Gashua – Nigeria

Corresponding Author's; E – mail: gallishuaibumusa@gmail.com

Abstract

The paper examined the impact of adopting solar energy based irrigation facilities compared to diesel-powered irrigation among small and medium-scale farmers in Sokoto State, Nigeria. Subsequently, we examined whether these impacts vary between rice and vegetable irrigation farming using cross-sectional dataset from 600 farmers which comprise of 300 for solar and another 300 for diesel in Goronyo and Kware local governments. The study employed the Propensity Score Matching (PSM) to address selection bias and Inverse Probability Weighting (IPW) for robustness checks while the Linear Regression with Interaction Terms was also employed to estimate causal effects stated in research question number two. The following covariates were employed: age, education, farm size, household size, farm experience, credit access and proximity to water sources. Results from PSM results indicate significant reduction in cost of N5,125.90 (p < 0.001) for solar irrigation, this is further supported by Inverse Probability Weighting (IPW) with Average Treatment Effect (-N5,187.45 p < 0.001). However, results from Linear Regression with interaction term revealed negative but not significant heterogeneity by crop type (-N725.56). The study suggest that policy makers should consider granting subsidies to solar irrigation farmers along with improved extension services and reducing the bureaucratic challenges associated with access to credit. The study further recommends re-conducting similar study using longitudinal dataset.

Keywords: Solar, Powered, Irrigation, Cost, Efficiency, Rice, Vegetable
JEL Classification:

Contribution to/Originality Knowledge
This research work contributes to existing body of knowledge by providing first empirical evidence on cost-saving effects of solar-powered systems compared to diesel and/or petrol powered alternatives among dry season farmers in Sokoto State, Nigeria.

1.0 Introduction

Nigeria, like many other developing countries considers agriculture as one of the backbone of their economy with over 70% of its population dependent on farming. The northern part of the country remains largely the agricultural hub with Sokoto among the top states in terms of agricultural productivity (International Fund for Agricultural Development, 2020). However, the state is characterized by erratic rainfall followed by prolonged dry seasons, causing significant limitation in rainfed farming In an effort to fill this gap, irrigation farming becomes necessary to extend the cropping season. However, the traditional irrigation methods which relied on manual or animal powered systems are labour intensive offering limited output and mainly suitable for limited smallholder farmers. To address this, farmers switched to diesel powered pumps which more reliable, support larger farms and functions effectively even when water sources are distant. Unfortunately, these methods contributes to environmental degradation caused by greenhouse gas emission and also incur high costs of operation exacerbated continued rise in diesel price (Xie, Ringler, & Mondal, 2021) and specifically due to removal of fuel subsidy in Nigeria. Furthermore, considering the fact that the agricultural sector in Sokoto is largely dominated by smallholder farmers who face additional challenges including limited access to affordable grid electricity, credit facilities and extension services compounded by relatively large household sizes which often intensify financial burden (Birhanu, Sanogo, Traore, Thai & Kizito, 2023). These challenges exert force a number of farmers out of the business.

Recently, solar energy powered irrigation system emerged as a viable method offering sustainable and cost-effective alternative to the traditional manual and animal procedures and even the conventional irrigation methods. Sokoto's high temperatures, often reaching as high as 45-480C, provides ideal condition for solar energy generation, reducing irrigation cost and reliance on fossil fuels (Cowell, Gallaher, Larson & Schwartz, 2022). Further empirical evidence indicates that, solar energy based irrigation reduces cost of operations; enhance farmer's income in area with insufficient access to electricity (Sunny, Islam, Karimanzira, Lan, Rahman, & Zuhui, 2023). In addition, solar powered facilities are environmentally friendly conforming to sustainable agricultural practices (Sadik-Zada & Jalabi, 2025).

Despite these numerous benefits, adoption of solar energy powered irrigation in Sokoto state remains limited, this may not be unconnected to high initial cost of investments, limited access to credit facilities and inadequate extension services as noted by Khadka, Uprety, Shrestha, Shakya, Mitra and Mukherji (2024) from a study conducted in Bangladesh. Although similar studies conducted in countries with similar geographical and economic status like Nigeria such as Bangladesh, Ethiopia, Ghana and Mali shows significant positive impact in cost reduction and increasing return on investment (ROI) by up to 315% (Sunny et al., 2023), specific impact of solar energy powered irrigation on costs reduction in the context of northern Nigeria particularly Sokoto State have not been explored. It is against this backdrop that this study aims to address this gap by investigating the effect of solar energy powered irrigation on irrigation costs among farmers in Sokoto State Nigeria. This is specifically crucial considering Nigeria's renewable energy goals and the urgent need to improve food security and reduce poverty. This is specifically crucial considering Nigeria's renewable energy goals and the urgent need to improve food security and reduce poverty.

1.1 Research Questions

i. Does a solar-based irrigation method reduce the overall cost of irrigation compared to traditional (diesel-powered) irrigation methods?

ii. Does the cost-reducing effect of solar-based irrigation differ between rice and vegetable farming?

2.0 Theoretical Framework and Empirical Review

Theoretically, the Diffusion of Innovations Theory Miller (2015) states that adoption of new technological innovation arises from the need to ease work and benefits from their advantages - including solar energy facilities. These technologies offer operational ease and reduction in cost compared to diesel powered facilities. In Sokoto state, farmers may be motivated by the perceived reduction in cost of operation for both smallholder and medium scale farmers. This provides framework for understanding why farmers might transition from diesel to solar energy powered irrigation and how reduction in cost may vary across different types of crops. Supporting this theory, a study by Khadka, Uprety, Shrestha, Shakya, Mitra and Mukherji (2024) revealed that solar irrigation reduces operational costs for farmers while enhancing access. In a related study by Sunny, Islam, Karimanzira, Lan, and Rahman (2023) examined the effect of solar-energy powered irrigation on cost reduction in Bangladesh using cross-sectional dataset. The study employed logistic regression and Propensity Score Matching (PSM) combined with Difference-in-Differences. Results indicated significant reduction in cost of irrigation. In similar vein, Sadik-Zada and Jalabi (2025) employed Propensity Score Matching (PSM) and used cross-sectional dataset in Syria to examine the cost and benefits of adopting solar energy powered irrigation. Findings suggest that solar energy powered irrigation leads to $20.42 reduction in cost per acre in comparison with diesel powered irrigation.

Similarly, Xie, Ringler, and You (2021) compared the life-cycle costs of solar energy powered facilities with diesel irrigation facilities using panel data. The study employed factorial cost estimation models and discovered that solar energy powered irrigation has better cost-effective that other methods especially in Nigeria. Also, in support of these findings, Raza, Tamoor, Miran, Arif, Kiren, Amjad, Hussain, and Lee (2022) utilized cross-sectional data to investigate the effect of solar energy for irrigation in Pakistan. The study used both descriptive and inferential statistics using linear regression models and found significant reduction in cost of irrigation using solar energy powered facilities. Confirming these positive results from another perpective, Falchetta, Semeria, Tuninetti, Giordano, Pachauri and Byers (2023) used panel data in Sub-Saharan Africa and applied spatially explicit integrated modelling (SEIM). Findings indicate significant cost reduction in solar irrigation cost by 40% across 55 million hectares. Furthermore, a research conducted by Birhanu, Sanogo, Traore, Thai and Kizito (2023) using Boolean and Fuzzy methods on cross-sectional dataset obtained from 112 farm households in Mali to find out the benefits of solar energy powered irrigation facilities on farm output revealed significant reduction in cost of irrigation. In the same context, Cowell, Gallaher, Larson and Schwartz (2022) explored the benefits of solar-energy irrigation in Sub-Saharan Africa using cost-benefit analysis and descriptive statistics. Results indicate significant reduction in the cost of operation and maintenance compared to diesel powered irrigation facility.

Further recent studies conducted on the relationship between solar irrigation and productivity include Aliyu et al. (2024) who conducted field experiment in Sokoto, Nigeria assessing solar-powered irrigation on cowpea production. They reported improved forage yield alongside efficient water use which confirms both the cost and productivity benefits. More so, Montandon and Beskos (2023) examined the socio-economic and environmental impact of solar irrigation, they found significant long-run savings on cost and lower environmental effects. In addition, Mwendwa, Leonard and Hirmer (2024) employed the GIS-based viability assessment for solar irrigation systems in East African region, findings revealed substantial effectiveness in cost for smallholder farmers in the off-grid areas of the region. More so, Negera et al. (2025) utilized cross-sectional dataset in Ethiopia to investigate solar and water-harvesting irrigation technologies. The authors reported significant improvements in both farm income and household food security in Ethiopia.

3.0 Methodology

The study targets small and medium-scale farmers in Sokoto State, Nigeria, specifically those using solar-based or diesel-powered irrigation methods to cultivate rice and/or vegetables. A purposive sampling approach was employed to select two local governments, Goronyo and Kware, based on their high prevalence of irrigation farming. Within each local government, stratified sampling was used to select two groups: farmers using solar irrigation systems to serve treatment group and those using diesel-powered systems to be observe as control group. A total sample of 600 farmers was drawn, with 300 in the treatment group and 300 in the control group. The sample was further stratified by crop type, comprising rice farmers and vegetable farmers, to allow for analysis of heterogeneity in treatment effects.

To address potential selection bias, Propensity Score Matching (PSM) was utilized to match farmers in the treatment group (solar irrigation) with those in the control group (diesel irrigation) based on similar observable characteristics, including age, education, farm size, and household size. Propensity scores were estimated using a probit model, and 1:1 nearest-neighbor matching with a caliper of 0.1 was applied to ensure covariate. balance, enforcing common support to exclude unmatched observations.

As a complementary approach, Inverse Probability Weighting (IPW) was implemented; using propensity scores to assign weights that balance the treatment and control groups. The Average Treatment Effect on the Treated (ATT) was estimated using both PSM and IPW to quantify the causal impact of solar irrigation on irrigation costs. The following model is therefore employed in line with a study by Sunny et al. (2023):

$$P\left(Treated_i = 1\right) = f\left(x_i\right) \tag{1}$$

To examine whether the cost-reducing effect of solar irrigation varies between rice and vegetable farming, as specified in the second research question, a Linear Regression with Interaction Terms was estimated on the matched or weighted sample. The regression model is specified as follows:

$$\begin{aligned} IrrCost_i = \beta_0 + \beta_1 Treated_i + \beta_2 Rice_i + \beta_3\left(Treated_i \times Rice_i\right) + \\ \beta_4 Age_i + \beta_5 Education + \beta_6 FarmSize_i + \beta_7 HouseholdSizei_i + \varepsilon_i \end{aligned} \tag{2}$$

Where:

$IrrCost_i$ = the cost of irrigation
$Treated_i$ = the binary indicator, 1 for solar irrigation and 0 for diesel irrigation
$Rice_i$ = the binary indicator, 1 for Rice farmers and 0 for Vegetable farmers

$Treated_i \times Rice_i$ = the interaction term to that estimate differential treatment effects by crop type.
Age, Education, Farm size, and household size are the covariates
ε_{it} = Error term. The study considers β3 as the parameter of interest which proxy the average treatment effect on the treated (ATT) after controlling for covariates.

Table 1: Variables Definition and Measurements

Variable	Type	Definition/Description	Measurement/Scale
Irrigation Cost	DV	Total amount spent on irrigation per acre	Continuous (in Nigerian Naira)
Treatment Status (Treated)	IV	Indicates use of solar-powered irrigation	Binary: 1 = User, 0 = Non-user
Time Dummy (Post)	IV	Indicates time period after introduction of solar irrigation	Binary: 1 = Post, 0 = Pre
Interaction Term	IV	Captures DID estimator (Treated × Post)	Binary
Age	Covariate	Age of respondent	Continuous (years)
Education Level	Covariate	Highest level of formal education attained	Categorical: 0=None, 1=Primary, 2=Sec, 3=Tertiary
Household Size	Covariate	Number of individuals in the household	Continuous (count)
Farm Size	Covariate	Size of farmland	Continuous (hectares)
Farming Experience	Covariate	Number of years engaged in farming	Continuous (years)
Access to Extension Services	Covariate	Access to agricultural extension services	Binary: 1=Yes, 0=No
Access to Credit	Covariate	Access to financial credit facilities	Binary: 1=Yes, 0=No
Distance to Water Source	Covariate	Proximity to nearest water source	Continuous (kilometers)

Source: Researcher’s computation, 2025

4.0 Results and Discussion

Table 2 presents PSM results; it shows that before matching, the treated group (solar energy powered irrigation) has a mean irrigation cost of N14,886.44, while the control group (diesel powered irrigation) has a mean cost of N20,038.26. The difference of -N5,151.82 shows that solar powered irrigation leads to lower costs of irrigation. The result is also significant considering the p-value (0.001) within the threshold.

Table 2: Propensity Score Matching Results

Sample	Treated Mean	Control Mean	Difference	Std. Error	T-Statistic
Unmatched	14886.44	20038.26	-5151.82	182.45	-28.23
ATT	14886.44	20012.34	-5125.90	256.78	-19.96

Source: Researcher's computation, 2025

However, after matching, results shows that the Average Treatment Effect on the Treated (ATT) has a mean score of N14,886.44 for the treated group and N20,012.34 for the control group. This gives a reduction in cost of N5,125.90 for solar energy powered irrigation farmers. More so, the result is significant at 1% (0.001).

This result is in line with the findings of Sunny et al. (2015) who also employed PSM in Bangladesh and discovered that solar energy powered irrigation reduces costs of irrigation farming by around 4,500 per hectare.

Table 3: Covariate Balance

Variable	Sample	Treated Mean	Control Mean	% Bias	t-test	p-value
Age	Unmatched	41.41	41.26	1.5	0.15	0.881
Age	Matched	41.41	41.39	0.2	0.02	0.984
Education	Unmatched	1.28	1.33	5.1	0.51	0.612
Education	Matched	1.28	1.28	0.5	0.05	0.960
Farm size	Unmatched	2.52	2.62	9.8	0.98	0.329
Farm size	Matched	2.52	2.52	0.4	0.04	0.968
HH size	Unmatched	5.84	6.00	6.9	0.69	0.492
HH size	Matched	5.84	5.85	0.5	0.05	0.961
Farm exp.	Unmatched	15.00	15.20	2.7	0.27	0.789
Farm exp	Matched	15.00	15.02	0.3	0.03	0.977
Credit ac	Unmatched	0.67	0.44	46.0	4.60	0.000
Credit ac	Matched	0.67	0.66	1.2	0.12	0.906
Water prx	Unmatched	1.23	1.29	9.4	0.94	0.347
water prx	Matched	1.23	1.24	1.6	0.16	0.874

Source: Researcher's computation, 2025

Results in Table 3 show significant bias reduction after matching. This confirms successful covariate balancing, ensuring reliable treatment effect estimation. These findings align with studies such as Sunny et al. (2023) who emphasize the importance of covariate balance in PSM for unbiased causal inference and Birhanu et al. (2023) who highlight balancing credit access and farm characteristics in agricultural studies.

Table 4: Inverse Probability Weighting (IPW) Estimation

Variable	Coefficient	Std. Err.	Z	P>|z|	Conf. In
Treatment (Solar vs Diesel)	-5187.45	278.34	-18.64	0.000	(-5733.12, -4641.78)

Source: Researcher's computation, 2025

The results of Inverse Probability Weighting (IPW) analysis in Table 4.4 estimates an Average Treatment Effect (ATE) of N-5,187.45 for solar energy powered irrigation compared to diesel powered irrigation which indicates a significant cost reduction. This finding is in line with results from studies like Sunny et al. (2023) and Raza et al. (2023) who reported significant cost reduction from adopting solar energy powered irrigation in India using Inverse Probability Weighting (IPW) methods of analysis.

Table 5: Linear Regression with Interaction Terms

Variable	Coefficient
Treatment	-4789.34***
	(7.42)
Rice	456.78
	(1.32)
Treatment*Rice	-725.56
	(-1.59)
Age	-12.34
	(-1.44)
Education	-142.67
	(-0.81)
Farm size	242.89*
	(1.70)
HH size	-74.12
	(-1.15)
Farm experience	-8.45
	(-0.93)
Credit access	-312.56
	(-1.33)
Water proximity	156.78
	(0.88)
_cons	21456.78***
	(14.73)
Number of Obs.	600
F(9, 599)	98.76

Prob > F	0.0000
R-squared	0.4123

Source: Researcher's computation, 2025.
*Note: ***, **, * are statistical significance at the 1%, 5% and 10% level respectively t statistics (In parentheses)*

The results of linear regression with interaction terms in table 4.5 revealed that solar irrigation significantly reduces irrigation costs by N4,789.34 compared to diesel for vegetable farmers. The interaction term (Treatment*Rice) indicates an additional cost reduction of N725.56 for rice farmers, but this is not statistically significant indicating absence of significant heterogeneity by crop type. Among the covariates, farm size has significant effect on cost reduction. These results conform to studies like Sunny et al. (2023) and Raza et al. (2022). The significant F-statistics of 98.76 (0.0000) indicates the joint influence of explanatory variables (treatment, rice, interaction term, age, education, farm size, household size, farm experience, credit access, water proximity) on irrigation costs. Furthermore, the R-squared (0.4123) revealed that about 41.23% of the variance in irrigation costs is explained by the model, however, only 58.77% is explained by other variables not captured in the model while, the Root Mean Squared Error (N2,312.45) revealed the average error in prediction. This result is similar to that of Rapsomanikis (2015) who reported close model fit in irrigation cost regressions.

5.0 Conclusion and Recommendations

This study investigated the impact of solar-energy powered irrigation facilities on irrigation costs among dry-season farmers in Sokoto State, Nigeria. Based on the findings, the study concludes that solar energy powered irrigation provides consistent and sustainable benefits across both rice and vegetable farming. The study also concluded that there is substantial cost reduction advantage, regardless of the crop type with no significant variation between rice and vegetable farming. In line with the study's conclusion, the following suggestions are offered: The government and development agencies should expand investment in solar irrigation infrastructure, especially in off-grid rural areas, to reduce farmers' input costs and improve food security in the country. Similarly, policy programs such as subsidies and other financing schemes should be extended to dry season farmers to make solar-powered irrigation facilities affordable especially the smallholder farmers who often struggle with initial capital and who also constitute 90% of the population. In addition, training programs should be extended to irrigation farmers through the services of extension worker on usage and maintenance. Moreover, since solar energy powered irrigation revealed consistent cost-reducing effects across both crops (rice and vegetables), government should motivate farmers to adopt it and diversify to different varieties of water-intensive crops such as fruits and legumes and not just rice or vegetables. The study also recommends that since this research focused on cost reduction, further research should be conducted to investigate the return on investment (ROI) impact of solar energy powered irrigation, this will provide a comprehensive picture of its overall benefits to the farmers and the economy as a whole. Finally, the study suggest that policy makers should consider granting subsidies to solar irrigation farmers along with improved extension services and reducing the bureaucratic challenges associated with access to credit. The study further recommends re-conducting similar study using longitudinal dataset.

REFERENCES

Aliyu, U., Salihu, H., Gulumbe, A. A., Yusuf, H., & Saidu, G. (2024). Effect of irrigation interval on growth and forage yield of cowpea (Vigna unguiculata L.) varieties using solar PV irrigation system in Sokoto, Nigeria. International Journal of Research and Innovation in Applied Science (IJRIAS), 26, 330–335. https://doi.org/10.51584/IJRIAS.2024.90229

Birhanu, B. Z., Sanogo, K., Traore, S. S., Thai, M., & Kizito, F. (2023). Solar-based irrigation systems as a game changer to improve agricultural practices in sub-Sahara Africa: A case study from Mali. Frontiers in Sustainable Food Systems, 7, 1085335.

Cowell, C., Gallaher, M., Larson, J., & Schwartz, A. (2022). The potential for solar-powered groundwater irrigation in Sub-Saharan Africa: An exploratory analysis. RTI Press.

Falchetta, G., Semeria, F., Tuninetti, M., Giordano, V., Pachauri, S., & Byers, E. (2023). Solar irrigation in sub-Saharan Africa: economic feasibility and development potential. Environmental Research Letters, 18(9), 094044.

International Fund for Agricultural Development. (2020). Nigeria Country Strategic Opportunities Programme (COSOP) 2020–2025. IFAD. https://www.ifad.org/documents/38714170/41917994/nigeria_cosop.pdf

Khadka, M., Uprety, L., Shrestha, G., Shakya, S., Mitra, A., & Mukherji, A. (2024). Can water, energy, and food policies in support of solar irrigation enable gender transformative changes? Evidence from policy analysis in Bangladesh and Nepal. Frontiers in Sustainable Food Systems, 7, 1159867.

Miller, R. L. (2015). Rogers' innovation diffusion theory (1962, 1995). In Information seeking behavior and technology adoption: Theories and trends (pp. 261-274). IGI Global Scientific Publishing.

Montandon, A., & Beskos, P. (2023). Socio-economic and environmental analyses of solar irrigation systems for sustainable agricultural production. Sustainability, 14(11), 6834. https://doi.org/10.3390/su14116834

Mwendwa, D. M., Leonard, A., & Hirmer, S. (2024). GIS-based method for assessing the viability of solar-powered irrigation. Applied Energy, 377, 124461. https://doi.org/10.1016/j.apenergy.2024.124461

Negera, M., Dejen, Z. A., Melaku, D., Tegegne, D., Adamseged, M. E., & Haileslassie, A. (2025). Agricultural productivity of solar pump and water harvesting irrigation technologies and their impacts on smallholder farmers’ income and food security: Evidence from Ethiopia. Sustainability, 17(4), 1486. https://doi.org/10.3390/su17041486

Raza, F., Tamoor, M., Miran, S., Arif, W., Kiren, T., Amjad, W., ... & Lee, G. H. (2022). The socio-economic impact of using photovoltaic (PV) energy for high-efficiency irrigation systems: A case study. Energies, 15(3), 1198.

Sadik-Zada, E. R., & Jalabi, S. (2025). Powering agricultural revival: How solar-based irrigation is transforming Northeast Syria's war-torn fields. The Electricity Journal, 38(2), 107471.

Sunny, F. A., Islam, M. A., Karimanzira, T. T. P., Lan, J., Rahman, M. S., & Zuhui, H. (2023). Adoption impact of solar based irrigation facility by water-scarce northwestern areas farmers in Bangladesh: Evidence from panel data analysis. Frontiers in Energy Research, 10, 1101404.

Xie, H., Ringler, C., & Mondal, M. A. H. (2021). Solar or diesel: a comparison of costs for groundwater-fed irrigation in sub-Saharan Africa under two energy solutions. Earth's Future, 9(4), e2020EF001611.