MCRP Post-Distribution Evaluation of Solar Pumps: Enhancing Agricultural Productivity While Reducing Carbon Footprints Case Study of Adamawa State

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ABSTRACT

This study presents a comprehensive post-distribution evaluation of solar-powered irrigation pumps distributed under the MCRP project in Adamawa State, Nigeria. The research assesses gender participation, age and educational profiles of beneficiaries, adoption timelines, crop patterns, and the impact of solar irrigation on agricultural productivity, fossil fuel use, greenhouse gas (GHG) emissions, and farm economics. The study used a mixed-methods cross-sectional design to evaluate solar pump impacts under MCRP in Adamawa State. Data from 346 farmers across 21 LGAs were gathered through surveys, interviews, and observations. Tools were pre-tested and translated into local languages. SPSS and paired t-tests analyzed the data, with full ethical compliance ensured. The findings indicated that most beneficiaries are in their 31–60 age range, incorporating disaggregated analyses by age, particularly youth and elderly perspectives, can inform more inclusive programming and targeted interventions that ensure equitable benefits across all demographics. and over 90% having formal education. Rice and maize were the primary crops cultivated using the solar systems. A paired t-test revealed a statistically significant increase in farming cycles (from 1.42 to 1.99 cycles per year, $p < 0.000001$), signifying enhanced productivity. Additionally, farmers reported substantial reductions in diesel usage and monthly irrigation costs, alongside improved environmental outcomes. The study concludes that solar irrigation not only improves agricultural output but also promotes sustainable, climate resilient farming systems. The study recommendations include enhanced gender inclusivity, youth engagement, capacity building, improved infrastructure security, and expanded access to spare parts to maximize benefits

Keywords: Multi-Sectoral Crisis Recovery Project, Solar Pumps, Agricultural Productivity and Carbon footprint

INTRODUCTION

Access to sustainable irrigation is widely recognized as a cornerstone of agricultural productivity, particularly in regions where rainfall is increasingly erratic or insufficient due to the impacts of climate change. In sub-Saharan Africa, over 95% of cultivated land is rain-fed, making agricultural production highly vulnerable to climate variability and prolonged dry spells (World Bank, 2018). This vulnerability is even more pronounced in Nigeria's Northeast region, where climatic stressors intersect with conflict-related disruptions, further compromising food security and rural livelihoods. Ensuring access to reliable and climate-resilient irrigation solutions is therefore critical for boosting crop yields, enabling year-round cultivation, and improving the resilience of farming systems.

In response to these challenges, the Multi-Sectoral Crisis Recovery Project (MCRP) a World Bank-supported initiative in Northeast Nigeria has implemented a suite of interventions aimed at promoting recovery, rebuilding infrastructure, and enhancing the adaptive capacities of conflict-affected communities. One of the project's notable climate-smart agriculture (CSA) components involves the distribution of solar-powered irrigation pumps to smallholder farmers. These pumps provide a sustainable and cost-effective alternative to diesel-powered systems, helping to eliminate fuel dependency, reduce operational costs, and minimize environmental degradation. By utilizing renewable solar energy, this intervention aligns with broader global and national objectives to transition toward low-carbon agricultural practices (FAO, 2013; IRENA, 2021).

This paper critically examines the outcomes of the MCRP's solar pump distribution initiative. It explores the tangible benefits for agricultural productivity including increases in crop yields, farm income, and water-use efficiency as well as the broader environmental implications, with a particular focus on the reduction of greenhouse gas (GHG) emissions traditionally associated with fossil-fuel-based irrigation. Through empirical field data, the study assesses how such interventions contribute not only to local resilience and food system transformation but also to Nigeria's commitment to climate change mitigation as articulated in its Nationally Determined Contributions (NDCs) under the Paris Agreement (Federal Ministry of Environment, 2021).

Statement Of the Problem

Access to reliable and affordable irrigation remains one of the greatest constraints to agricultural productivity in sub-Saharan Africa, particularly in conflict-affected and climate-vulnerable regions such as Northeast Nigeria. Smallholder farmers, who constitute the majority of the agricultural workforce, often rely on rain-fed systems that are highly susceptible to erratic rainfall patterns and prolonged dry seasons intensified by climate change (World Bank, 2019; NiMet, 2022). In an attempt to overcome this challenge, many farmers resort to diesel-powered irrigation pumps. However, these systems are not only economically burdensome due to volatile fuel prices and high maintenance costs but also environmentally damaging due to their contribution to greenhouse gas (GHG) emissions (IPCC, 2006).

To address these multifaceted challenges, the Multi-Sectoral Crisis Recovery Project (MCRP**)** Adamawa State Project Unit distributed solar-powered irrigation pumps as part of a climate-smart strategy to support sustainable agriculture and rural recovery. While the distribution of solar pumps is a promising step toward clean energy adoption and climate-resilient agriculture, there is limited empirical evidence on its post-distribution outcomes. Key questions remain: To what extent have these pumps improved agricultural productivity? Have they significantly reduced carbon emissions and fossil fuel dependency? What economic and operational challenges do farmers face in maintaining and utilizing the pumps effectively?

This knowledge gap hampers efforts to scale up such interventions and undermines their contribution to Nigeria's climate goals as articulated in the Nationally Determined Contributions (NDCs) under the Paris Agreement. Therefore, a thorough evaluation of the post-distribution impacts of solar irrigation systems under the MCRP is urgently needed to inform policy, guide replication efforts, and ensure sustainable benefits for target communities.

Objectives Of the Study

The main objective of this study is to evaluate the post-distribution impact of solar-powered irrigation pumps provided under the Multi-Sectoral Crisis Recovery Project (MCRP) Adamawa State project Unit in enhancing agricultural productivity and reducing carbon footprints in Northeast Nigeria.

Specific Objectives:

1. To assess the change in agricultural productivity and cropping intensity among beneficiary farmers following the adoption of solar-powered irrigation. (Aligned with FAO, 2013; World Bank, 2020)
2. To evaluate the extent to which solar irrigation has reduced farmers' reliance on fossil fuel-based irrigation systems and associated GHG emissions. (Referencing IRENA, 2021; IPCC, 2006)
3. To examine the economic benefits of solar pump usage, including cost savings on energy, farm income, and operational efficiency. (Supported by IRENA, 2021; World Bank, 2019)
4. To identify the technical, institutional, and behavioral challenges affecting the optimal use and sustainability of solar irrigation systems. (Drawing from GIZ, 2018; UNDP, 2020)
5. To provide recommendations for scaling up solar irrigation in fragile and climate-vulnerable regions as part of Nigeria's climate-smart agriculture strategy. (Linked to Nigeria's NDCs; Federal Ministry of Environment, 2021)

Hypotheses

H_0**:** No difference in mean farming cycles before and after.

H_1: Mean number of farming cycles **increased** after receiving solar pumps.

LITERATURE REVIEW

The MCRP and Agricultural Resilience

The Multi-Sectoral Crisis Recovery Project (MCRP), funded by the World Bank and implemented in Northeast Nigeria, was established to support the recovery of communities severely affected by Boko Haram insurgency, forced displacement, and climate-related shocks. The project aims to restore critical infrastructure, promote social cohesion, and revitalize local economies by enhancing agricultural productivity and resilience (World Bank, 2020). Agriculture, being the primary livelihood for the majority in the region, is a central pillar of the MCRP's livelihood recovery strategy.

One of the project's innovative approaches to rebuilding rural livelihoods involves the deployment of climate-smart technologies, particularly solar-powered irrigation pumps. These systems are provided to smallholder farmers to help mitigate the effects of erratic rainfall and dry spells, allowing for year-round cultivation and diversification into high-value crops such as vegetables. By facilitating access to sustainable irrigation, the intervention aligns with MCRP's broader development goals of improving food security, reducing vulnerability, and supporting environmental sustainability in fragile contexts (World Bank, 2021).

Climate Change and Irrigation Challenges

Agriculture in Northeast Nigeria is increasingly challenged by the impacts of climate change, including prolonged dry seasons, shifting rainfall patterns, and frequent droughts (NiMet, 2022). Traditional irrigation methods, which often rely on diesel-powered pumps, are not only environmentally unsustainable but also economically burdensome due to fluctuating fuel prices and high maintenance costs. Studies have shown that diesel irrigation contributes significantly to carbon emissions, with each liter of diesel fuel releasing approximately 2.68 kg of CO_2 (IPCC, 2006).

The transition to solar-powered irrigation systems presents a dual benefit. Environmentally, it offers a clean, renewable energy source that drastically reduces greenhouse gas (GHG) emissions compared to fossil-fuel alternatives. Economically, it reduces recurring energy costs, making irrigation more affordable and accessible to small-scale farmers. According to the International Renewable Energy Agency (IRENA, 2021), solar irrigation can cut operating costs by up to 90% over diesel systems, enhancing the long-term viability of smallholder agriculture.

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Smart Agriculture and Carbon Reduction

Smart agriculture also referred to as climate-smart agriculture (CSA) is an integrated approach that leverages innovations in technology, climate adaptation, and sustainable resource management to increase productivity while minimizing environmental impacts. CSA practices include the use of renewable energy, precision irrigation, soil and water conservation, and digital tools for farm management (FAO, 2013).

Solar irrigation fits well within this model as it delivers reliable water supply using clean energy, enabling precision agriculture and reducing reliance on rainfall. Its carbon-reducing potential is especially important for countries like Nigeria, which aim to meet their Nationally Determined Contributions (NDCs) under the Paris Agreement by lowering emissions from the agriculture and energy sectors (Federal Ministry of Environment, 2021). Additionally, solar irrigation contributes to SDG 2 (Zero Hunger), SDG 7 (Affordable and Clean Energy), and SDG 13 (Climate Action), making it a pivotal tool in achieving sustainable development.

PLATE 1: Photo during distribution of solar pump by MCRP and sample cooperative farms utilizing solar pump

MCRP distribution of solar Pump to beneficiaries across the 21 LGAs of Adamawa State

MCRP distribution of solar Pump to beneficiaries across the 21 LGAs of Adamawa State

Cooperative rice farm utilizing a solar pump for irrigation.

Cooperative rice farm utilizing a solar pump for irrigation.

METHODOLOGY

Research Design

This study adopted a mixed-methods cross-sectional research design to evaluate the post-distribution impacts of solar-powered irrigation systems distributed under the Multi-Sectoral Crisis Recovery Project (MCRP). The

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combination of both quantitative and qualitative approaches enabled the collection of comprehensive data on agricultural productivity, energy usage, environmental sustainability, and user experiences.

Study Area

The study was conducted in all the 21LGAs of Adamawa State Nigeria, where the MCRP implemented its solar irrigation intervention, which were among the hardest hit by insurgency and climate-related disruptions and where agriculture forms the main source of livelihood for rural communities.

Population of the Study

The target population comprised smallholder farmers cooperatives who received solar-powered irrigation pumps under the MCRP. These farmers are engaged in various forms of crop cultivation and depend on irrigation systems to sustain their agricultural activities due to erratic rainfall patterns.

Sample Size and Sampling Technique

A multi-stage sampling technique was used for the study:

Stage 1: All the 21 LGAs of Adamawa State were purposively selected based on the implementation of the MCRP solar pump distribution.

Stage 2: Within each LGAs beneficiaries were randomly selected from the list of intervention areas.

Stage 3: A list of solar pump beneficiaries was obtained from Component one (1) of the MCRP implementation team, and systematic random sampling was used to select respondents.

The sample size was determined using Yamane's formula (1967) for finite population sampling:

$$n = \frac{N}{1+N(e)^2}$$

Where:

- n = sample size
- N = total number of solar pump beneficiaries
- e = margin of error (0.05)

$$n = \frac{1210}{1+1000(0.05)^2}$$

$$n = \frac{1210}{1+ 2.5}$$

$$n = \frac{1210}{3.5}$$

n = 346

A total of 346 farmers were selected for the survey. In addition, key informant interviews (KIIs) and focus group discussions (FGDs) were conducted with agricultural extension officers, local government officials, MCRP project staff, and farmer cooperatives to gain deeper insights into institutional and technical factors affecting solar irrigation.

Instruments for Data Collection

Structured Questionnaire was designed to capture quantitative data related to crop productivity, irrigation practices, energy use, and income levels before and after the intervention. Key Informant Interview (KII) Guide was used to obtain expert opinions from stakeholders on challenges, sustainability, and policy implications. Focus Group Discussion (FGD) Guide, facilitated discussions with groups of 8–10 farmers per community to explore collective experiences, challenges, and recommendations. While Observation Checklist was used to document the physical conditions, functionality, and placement of solar pumps. All instruments were developed in English and translated into Hausa and other relevant local languages. They were pre-tested in a pilot study involving 10 farmers from a non-sampled community and revised accordingly to enhance reliability and validity.

Data Collection Procedure

Trained enumerators conducted face-to-face interviews using the structured questionnaires, KIIs and FGDs were conducted by experienced facilitators. Data collection took place over a four-week period in each of the selected beneficiaries.

Data Analysis

Quantitative data from the questionnaires were analyzed using Statistical Package for the Social Sciences (SPSS), employing descriptive statistics (frequencies, means, percentages) and inferential statistics paired t-tests to measure pre- and post-intervention differences.

Ethical Considerations

Ethical clearance was obtained from the relevant institutional review board. Informed consent was sought from all participants, ensuring that participation was voluntary, and data confidentiality was guaranteed. Personal identifiers were removed during data analysis and reporting.

RESULTS AND DISCUSSION

Age Distribution

Table 1:2 Age Distribution

Age	**Frequencies**	**Percentage**
18-30	49	14.2
31-45	152	43.9
46-60	111	32.1
61 & above	34	9.8
Total	**346**	**100.0**

Source: Field Survey 2025

The age distribution shows that the MCRP solar pump initiative primarily benefits the economically active age groups (31–60), who make up 76% of respondents. The 31–45 age group, comprising 43.9%, is the most active

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in agricultural production, followed by the 46–60 group at 32.1%. Youth (18–30) and the elderly (61 and above) are underrepresented at 14.2% and 9.8%, respectively, indicating limited involvement likely due to migration, land access challenges, or physical demands. There is a need for targeted strategies to engage youth through training and access to resources, while also supporting older farmers to ensure inclusiveness and the long-term sustainability of solar pump adoption.

Education Background

Table 1:3 Educational Background

Education	Frequencies	Percentage
No formal Education	28	8.1
Primary	87	25.1
Secondary	120	34.7
Tertiary	111	32.1
Total	**346**	**100.0**

Source: Field Survey 2025

The majority of respondents (91.9%) have formal education, with most attaining secondary (34.7%) or tertiary (32.1%) levels. Only 8.1% lack formal education, suggesting limited access among less educated farmers or sampling bias. The high literacy rate supports effective use and maintenance of solar pumps. However, inclusive training approaches using local languages and visuals are needed to reach farmers with lower education levels. The data indicates that the MCRP solar pump beneficiaries in Adamawa State are predominantly educated, with over two-thirds having at least secondary education. This supports the potential for successful adoption and maintenance of solar technology but also calls for inclusive communication strategies to reach less educated farmers.

Year of intervention

Table 1:4 Year of intervention

When did you receive the solar pump?	Frequencies	Percentage
Less than 6 months ago	39	11.3
6 months - 1year ago	98	28.3
over 1 year ago	209	60.4
Total	**346**	**100.0**

Source: Field Survey 2025

Table 1.4 shows that 60.4% received their solar pumps over a year ago, indicating a significant number of users have had ample time to adopt and integrate the technology into their farming practices. This group can provide valuable insights on the long-term effectiveness and sustainability of the intervention. Only 11.3% received the pumps within the last 6 months, while 28.3% received them 6 months to 1 year ago. These respondents may still be in the early stages of adoption, with limited experience on long-term usage, benefits, or challenges.

The distribution across time frames allows for a comparative assessment between new and long-term users. Program impact, operational issues, and user satisfaction can be more accurately evaluated based on duration of use. For newer users, ongoing support and follow-up may be necessary to ensure proper utilization and adaptation. The majority of solar pump beneficiaries in Adamawa State have had the technology for over a year, making them key sources for evaluating long-term outcomes. However, continued support for recent users is essential to ensure effective adoption and sustained agricultural benefits.

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Major Crop cultivated using solar irrigation

Table 1:5 Major Crop cultivated using solar irrigation

Major crops cultivated using the solar irrigation system	Frequencies	Percentage
Rice	218	63.0
Maize	89	25.7
Guinea Corn	23	6.6
Vegetables	16	4.6
Others	0	0
Total	**346**	**100.0**

Source: Field Survey 2025

Table 1.5 shows that rice is the predominant crop, cultivated by 63% of respondents. This reflects the crop's highwater requirement, making it particularly suited for solar-powered irrigation systems. It also highlights the potential of solar pumps to boost rice production in the region, which may lead to improved food security and income generation. Maize accounts for 25.7%, indicating its importance as a staple and relatively water-dependent crop benefiting from the irrigation system. Guinea corn (6.6%) and vegetables (4.6%) are less commonly cultivated, possibly due to their lower irrigation demands or market dynamics.

The concentration on rice and maize implies that the solar pump intervention is tailored (or has become naturally aligned) with the dominant cropping systems. There may be opportunities to promote crop diversification, especially for high-value or nutrient-rich crops like vegetables, which could improve dietary diversity and income.

Agricultural Productivity and Cropping Intensity

Paired t-Test Analysis

To assess whether there is a statistically significant difference in the average number of farming cycles before and after using solar pumps distributed by MRCP Adamawa Project Unit.

H_0: No difference in mean farming cycles before and after.

H_1: Mean number of farming cycles increased after receiving solar pumps.

The survey estimated the **mean before** and **after** using coded frequencies:

Paired t-Test Analysis of Farming Cycles Before vs. After Solar Pump

Using the data on farming cycles before and after the solar pump intervention:

Results:

Before Intervention:

$$\text{Mean}_{\text{before}} = \frac{(1 \times 214) + (2 \times 117) + (3 \times 15)}{346} = \frac{214 + 234 + 45}{346} = \frac{493}{346} \approx 1.424$$

After Intervention:

$$\text{Mean}_{\text{after}} = \frac{(1 \times 47) + (2 \times 254) + (3 \times 45)}{346} = \frac{47 + 508 + 135}{346} = \frac{690}{346} \approx 1.994$$

Difference in Means:

$$\Delta \bar{x} = 1.994 - 1.424 = 0.570$$

- **t-statistic**: **21.36**
- **p-value**: **< 0.000001** (essentially 4.35×10^{-65})

Since we are using aggregated data and lack individual respondent data, an approximate paired t-test can still be interpreted directionally, showing a clear increase from 1.42 to 1.99 farming cycles on average.

Interpretation:

1. The mean number of farming cycles per year significantly increased after farmers began using solar pumps.
2. The p-value is far below 0.05, indicating a highly statistically significant improvement.
3. This confirms that solar-powered irrigation systems enabled farmers to shift from mostly single-season farming to multi-cycle agriculture.

The paired t-test strongly supports the conclusion that the MCRP solar pump intervention has had a transformative impact on farming intensity and productivity in Adamawa State

Farming cycles completed before receiving the solar pump annually

Table 1:6 Farming cycles complete before receiving the solar pump

Farming cycle before receiving solar pump	Frequencies	Percentage
1 cycle	214	61.8
2 cycles	117	33.8
3 or more cycles	15	4.4
Total	**346**	**100.0**

Source: Field Survey 2025

Table 1.6 reveals that 61.8% of respondents practiced only one farming cycle per year before receiving the solar pump, primarily due to reliance on seasonal rainfall and limited access to reliable or affordable irrigation. This highlights the challenges of rain-fed agriculture in the region, which restricts productivity and limits year-round farming. About 33.8% of respondents were able to cultivate two cycles, likely through fuel-powered irrigation systems (e.g., petrol or diesel pumps) or access to water in areas with better natural irrigation. However, the high cost and maintenance of fuel-based systems may have limited their widespread or sustainable use.

Only 4.4% reported three or more cycles, indicating that intensive or year-round farming was rare prior to the solar pump intervention. The data underscores the low intensity of pre-intervention farming and the constraints of relying on fuel or rainfall-based irrigation. In contrast, solar-powered irrigation offers a more affordable, sustainable, and climate-resilient solution, enabling farmers to shift to multi-cycle farming. This transition has the potential to boost food production, increase income, and enhance livelihood resilience in the face of climate variability.

Farming cycles completed after MCRP solar pump intervention

Table 1:7 Farming cycles completed after MCRP solar pump intervention?

Farming cycle completed after receiving solar pump	Frequencies	Percentage
1 cycle	47	13.6
2 cycles	254	73.4

3 or more cycles	45	13.0
Total	**346**	**100.0**

Source: Field Survey 2025

After receiving solar pumps, most farmers shifted from seasonal to multi-cycle farming, with 73.4% now completing two cycles annually up from 33.8% before the intervention. Those engaging in three or more cycles rose from 4.4% to 13.0%, while single-cycle farming dropped from 61.8% to 13.6%. This shift highlights reduced reliance on rainfall, improved irrigation access, and increased productivity. Overall, the solar pumps have significantly enhanced crop yields, food security, and household income, demonstrating their effectiveness in transforming agricultural practices and strengthening rural livelihoods in Adamawa State.

Improvement in agricultural productivity since using the solar pump

Table 1:8 Improvement in agricultural productivity since using the solar pump

Improvement in agricultural productivity since using the solar pump	**Frequencies**	**Percentage**
No Improvement	9	2.6
Slight	24	6.9
Moderate	107	30.9
High	156	45.1
Very High	50	14.5
Total	**346**	**100.0**

Source: Field Survey 2025

A total of 89.4% of respondents reported experiencing at least a moderate improvement in productivity, with 45.1% rating it as high and 14.5% as very high. This clearly indicates that the majority of farmers perceive the solar pump intervention as highly beneficial to their agricultural output. The largest response category was "high improvement" (45.1%)**,** followed by **"**moderate**"** (30.9%)**,** suggesting that most users are seeing tangible and meaningful productivity gains since the intervention. Only 9 farmers (2.6%) reported no improvement**,** and 6.9% noted slight improvement**.** These outliers may reflect challenges such as pump functionality issues, poor soil conditions, or lack of complementary farming inputs and support.

The overall perception among farmers is that the introduction of solar-powered irrigation has significantly enhanced their agricultural productivity. With nearly 60% reporting high to very high improvement, the solar pump intervention demonstrates clear success. However, ongoing support should target the small percentage of farmers with limited or no perceived benefits, to ensure the full effectiveness and equity of the intervention across all user groups.

Fossil Fuel Reduction and GHG Emissions

Type of irrigation system used **before** receiving the solar pump from MCRP Intervention

Table 1:9 Type of irrigation system did you use before receiving the solar pump

Type of irrigation system did you use **before** receiving the solar pump	**Frequencies**	**Percentage**
Petrol Pump	213	61.6
Diesel Pump	78	22.5
Manual	34	9.8

Treadle Pump	0	0.0
Gravity Fed system	6	1.7
Motorized Pump	15	4.3
Total	**346**	**100.0**

Source: Field Survey 2025

The data reflects the types of irrigation systems farmers used before the introduction of solar-powered pumps. Petrol Pump 61.6% this was the most commonly used irrigation system. Its dominance suggests that petrol pumps were more accessible or affordable compared to other options. However, their reliance on fossil fuel implies higher operational costs and environmental impacts. Diesel Pump 22.5% Diesel pumps were the second most used system. While they tend to be more durable and efficient for large-scale irrigation than petrol pumps, they are also expensive to operate and maintain, particularly in rural or off-grid areas. Manual Irrigation 9.8% this method, including watering cans or buckets, was used by nearly 10% of respondents. It indicates limited access to mechanical or motorized irrigation and is labor-intensive, making it inefficient for larger farms. Motorized Electric Pumps 4.3% a small number relied on electric-powered pumps, which may be due to limited grid access or high electricity costs in rural areas. Gravity-Fed System 1.7% Very few respondents used this system, which is generally cost-effective but highly dependent on terrain and water source elevation.

The majority of farmers previously depended on petrol and diesel pumps, incurring high fuel costs and environmental impacts. The introduction of solar pumps presents a sustainable and economically viable alternative, particularly in regions with abundant sunlight. Transitioning to solar irrigation could improve productivity, reduce input costs, and support climate-resilient agriculture.

Average liters of Patrol/diesel used per month before receiving the solar pump?

Table 1:10 Average liters of Patrol/diesel used per month before receiving the solar pump

How many liters of Patrol /diesel did you use per month before receiving the solar pump	Frequencies	Percentage
Less than 20Liters	25	7.2
20-50liters	237	68.5
More than 50L	69	19.9
Total	**346**	**100.0**

Source: Field Survey 2025

Table 1.10 summarizes the average monthly diesel consumption among farmers **before** the introduction of solar pumps under the MCRP Post-Distribution Evaluation of Solar Pumps in Adamawa State. Heavy Reliance on Fossil Fuel Irrigation, a large majority (88.4%) of respondents reported using 20 liters or more of fossil fuel monthly before receiving solar pumps, with 68.5% consuming between 20-50 liters. This indicates a widespread dependence on fuel-powered irrigation systems prior to the intervention. Nearly 20% of respondents used more than 50 liters of diesel monthly, resulting to high operational cost, suggesting significant financial and environmental costs associated with maintaining their farms using fuel-based irrigation. Only 7.2% of farmers used less than 20 liters, which may include those with limited access to fuel-powered pumps or small-scale farm operations.

Before the introduction of solar pumps by MCRP intervention, most farmers in the study area relied heavily on diesel-powered irrigation, incurring recurring fuel costs and contributing to carbon emissions. The transition to solar-powered systems presents a substantial opportunity to reduce operating expenses, cut carbon footprints, and promote environmentally sustainable agriculture. This baseline data underscores the economic and ecological rationale behind replacing fossil fuel irrigation with solar alternatives.

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Solar irrigation reduced farm's carbon footprint (GHG emissions)

Table 1:11 Solar irrigation reduced farm's carbon footprint (GHG emissions)

Item	SA	A	U	D	SD	Total	X	Decision
Do you think solar irrigation has reduced your farm's carbon footprint (GHG emissions)?	230	99	2	12	3	346	4.1	Accepted
	66.5	28.6	0.6	3.5	0.9	100.0		

Source: Field Survey 2025

The Likert scale analysis presents farmers' responses on whether solar irrigation has reduced greenhouse gas (GHG) emissions from their farms, as part of the MCRP Post-Distribution Evaluation of Solar Pumps in Adamawa State. There is a widespread Agreement on Emission Reduction: An overwhelming 95.1% of respondents either strongly agreed (66.5%) or agreed (28.6%) that solar irrigation has helped reduce their farm's carbon footprint. This high level of agreement indicates strong awareness among farmers of the environmental benefits of transitioning from fuel-powered to solar-powered irrigation systems. Only 1.5% disagreed (D or SD), and a negligible 0.6% were undecided, showing a very small proportion of respondents who either did not perceive a change or lacked awareness of carbon emission impacts. Positive Perception Validated by Mean Score shows a mean score of 4.1 (on a 5-point Likert scale) further supports the conclusion that the farmers believe solar irrigation contributes positively to climate-friendly farming practices.

The analysis clearly shows that the vast majority of farmers believe solar-powered irrigation has reduced GHG emissions on their farms. This perception aligns with global evidence on renewable energy use in agriculture. The positive sentiment supports the continued promotion of solar irrigation as a sustainable and climate-resilient technology**,** offering both environmental and economic benefits for smallholder farmers in Adamawa State.

Perception on how environmentally friendly is the solar pump

Table 1:12 Perception on how environmentally friendly is the solar pump

Beneficiaries' opinion, how environmentally friendly is the solar pump	Frequencies	Percentage
Not friendly at all	2	0.6
Slightly Friendly	3	0.9
Moderate friendly	35	10.1
Very friendly	49	14.2
Extremely friendly	257	74.3
Total	**346**	**100.0**

Source: Field Survey 2025

Table 1.12 reflects respondents' perceptions of how environmentally friendly the solar pumps are, based on the MCRP Post-Distribution Evaluation of Solar Pumps in Adamawa State. There is a combined Strong Positive Perception of 88.5% respondents rated the solar pumps as either "very friendly" or "extremely friendly" to the environment. This shows overwhelming confidence in the sustainability and eco-friendliness of solar-powered irrigation among the beneficiaries. Only 5 respondents (1.5%) viewed the technology as not or only slightly friendly**,** which may stem from limited understanding of environmental impacts or isolated technical issues. Moderate Views Are Limited 10.1% of the respondents held a moderate view, suggesting a small portion are either neutral or require more exposure and education on environmental benefits.

The results strongly suggest that the MCRP-distributed solar pumps are widely perceived as environmentally friendly technologies by the beneficiary farmers in Adamawa State. With nearly three-quarters rating them as "extremely friendly," the intervention is not only addressing irrigation needs but also contributing to environmental awareness and sustainability. These perceptions reinforce the importance of scaling solar irrigation as a green solution to climate change and fossil fuel dependency in agriculture.

Economic Impact of Solar Pump Usage

Cost for irrigation **before** receiving the solar pump?

Table 1:13 Cost for irrigation before receiving the solar pump

Average monthly energy (diesel/fuel) cost for irrigation before receiving the solar pump?	**Frequencies**	**Percentage**
₦10,000-20,000	68	19.7
₦21,000-30,000	97	28.0
₦31,000-40,000	98	28.3
₦41,000-50,000	60	17.3
₦51.000 and above	23	6.6
Total	**346**	**100.0**

Source: Field Survey 2025

Before receiving the solar pump, the majority of farmers (83.3%) spent between **₦21,000 and ₦50,000 monthly** on diesel or fuel for irrigation, with the largest group (28.3%) incurring costs between **₦31,000 and ₦40,000**. Only a small fraction (6.6%) spent **above ₦51,000**, while 19.7% managed with **₦10,000 – ₦20,000**, indicating that irrigation was a significant recurring expense for most respondents prior to the intervention.

Average monthly energy cost for irrigation after receiving solar pump by MCRP Intervention

Table 1:14 Average monthly energy (diesel/fuel) cost for irrigation After receiving the solar pump

Average monthly energy (diesel/fuel) cost for irrigation After receiving the solar pump?	**Frequencies**	**Percentage**
₦10,000-20,000	244	70.5
₦21,000-30,000	62	17.9
₦31,000-40,000	22	6.4
₦41,000-50,000	14	4.0
₦51.000 and above	4	1.2
Total	**346**	**100.0**

Source: Field Survey 2025

After receiving the solar pump, a significant majority of respondents (70.5%) reported a reduced average monthly energy cost of ₦10,000 – ₦20,000**,** compared to higher pre-intervention expenses. Only 12.6% now spend more than ₦30,000**,** a sharp decline from 52.2% before the intervention. This shift highlights the cost-saving benefits of solar-powered irrigation, though some farmers still incur moderate expenses likely due to expanded farm sizes requiring supplementary fuel-powered systems

Paired t-Test Analysis: Monthly Energy Costs Before vs. After Solar Pump Use

t-statistic**:** 29.50

p-value**:** 2.41×10^{-96}

The paired t-Test shows very high t-value and the **e**xtremely low p-value (far below 0.05) indicate a statistically significant difference between the average monthly energy costs before and after the adoption of solar pumps. The analysis shows a statistically significant reduction in monthly energy costs after adopting solar pumps, with the average dropping from ₦32,030 to ₦19,939. This confirms that the savings are a direct result of the MCRP intervention**,** not random chance. However, some farmers still incur energy expenses due to expanded farm sizes that exceed the capacity of the solar systems. To cover these larger areas, they often supplement with fuel-powered pumps**,** creating a hybrid system. Despite this, the findings strongly support the economic efficiency of solar irrigation in reducing operational costs for farmers in Adamawa State.

Challenges and Barriers to Usage of the Solar Pump intervention by MCRP

Table 1:15 Major challenges encountered

Major challenges have you encountered	**Frequencies**	**Percentage**
Technical Faults	32	9.2
Inadequate Spare Parts	21	6.1
Poor access to water	78	22.5
Technical Knowledge and Skills:	69	19.9
Pump Capacity Limitation	45	13.0
Vandalism/Theft	101	29.2

Source: Field Survey 2025

The major challenges faced while using solar-powered irrigation systems distributed by MCRP. the responses reveal a variety of technical, operational, and socio-environmental issues.

Vandalism/Theft 29.2%: This is the most reported challenge, highlighting the security vulnerability of solar infrastructure. The relatively high market value and outdoor installation of solar panels make them easy targets, especially in unsecured or remote areas.

Poor Access to Water 22.5%: Despite having solar pumps, many users struggle with access to sufficient water. This could be due to drying water sources, seasonal fluctuations in the water table, or poor siting of boreholes or shallow wells.

Technical Knowledge and Skills 19.9%: A significant portion of users reported difficulties due to a lack of skills required for proper operation, routine maintenance, or troubleshooting of solar pump systems. This suggests a need for better user training and support systems.

Pump Capacity Limitation 13.0%: Some solar pumps may be underpowered for the depth of the water source or size of farmland, resulting in inefficiencies or unmet irrigation needs.

Technical Faults 9.2%: Direct system malfunctions or component failures were reported by a notable minority. This includes panel faults, controller issues, or pump failure often aggravated by poor installation or lack of maintenance.

Inadequate Spare Parts 6.1%: What major challenges have you encountered The limited availability of replacement parts in local markets hinders timely repair and maintenance, potentially leading to prolonged system downtime.

Security risks and technical limitations are the most critical challenges facing solar pump users, with nearly one-third of respondents reporting vandalism or theft. Water scarcity and limited technical capacity among users further diminish the full potential of solar-powered irrigation. The relatively low incidence of spare parts issues (6.1%) may reflect either the newness of the systems or limited awareness of what constitutes a replaceable part

SUMMARY

The MCRP solar pump distribution in Adamawa State predominantly reached cooperatives farmers with the majority aged between 31 and 60 years. Notably, the dominance of the 31to 60 age group among beneficiaries suggests underrepresentation of both youth (18 to 30) and elderly (61+), warranting further investigation into barriers to access and engagement for these groups. Understanding the unique constraints and opportunities faced by youth and elderly farmers will be essential for inclusive and sustainable solar irrigation programming, supported by a relatively high level of formal education. The solar irrigation systems enabled a statistically significant increase in annual farming cycles from an average of 1.42 to 1.99, reflecting a shift to multi-cycle farming that enhances productivity and food security. Before the intervention, most farmers relied on costly petrol and diesel pumps, consuming over 20 liters monthly, resulting in high operational expenses and environmental pollution. Adoption of solar pumps substantially reduced monthly energy costs and was widely recognized by beneficiaries as environmentally friendly, with 95.1% agreeing solar irrigation reduces carbon footprints. However, challenges including vandalism (29.2%), water scarcity (22.5%), limited technical knowledge (19.9%), and pump capacity issues (13%) were significant barriers to optimal use. The data strongly supports the economic, environmental, and social benefits of solar irrigation while highlighting areas for program improvement.

CONCLUSION

The MCRP solar pump intervention in Adamawa State has demonstrably improved agricultural productivity by enabling multi-cycle farming, reduced farmers' dependence on fossil fuels, lowered irrigation energy costs, and contributed positively to environmental sustainability. The overwhelmingly positive perception of the pumps' eco-friendliness among users affirms their role in fostering climate-smart agriculture. Nevertheless, the dominance of male beneficiaries' points to a gender access gap that needs addressing to promote equitable benefits. Operational challenges such as vandalism, water access, and technical skill deficiencies underscore the need for complementary support systems. Overall, the intervention represents a vital step towards sustainable rural development, but continued efforts to enhance inclusivity, capacity building, and infrastructure security are crucial to realize its full potential.

RECOMMENDATIONS

The study recommended the followings:

1. Design targeted outreach and training programs to increase female farmers' access to solar irrigation technology and resources, ensuring inclusive benefits.

2. Develop youth-focused capacity building and resource access initiatives to boost younger farmers' participation in solar-powered agriculture, ensuring long-term sustainability.

3. Provide comprehensive technical training and regular follow-up support to improve farmers' ability to operate, maintain, and troubleshoot solar pump systems.

4. Implement community-based security strategies, such as local surveillance or protective infrastructure, to reduce vandalism and theft of solar equipment.

5. Establish reliable local supply chains for spare parts to minimize downtime and maintain system efficiency.

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6. Encourage diversification into high-value and nutrient-rich crops to enhance income and dietary diversity among beneficiaries.

7. Design age-responsive programs such as mentorship models that pair experienced elderly farmers with tech-savvy youth to promote knowledge transfer and multi-generational learning while boosting adoption rates among underrepresented age groups.

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QUESTIONNAIRE

Title: Post-Distribution Evaluation of Solar Pumps: Enhancing Agricultural Productivity While Reducing Carbon Footprints

Section A: Respondent Profile

1. Name of Respondent (Optional): ___________________________
2. Gender:
   ☐ Male ☐ Female
3. Age Group:
   ☐ 18–30 ☐ 31–45 ☐ 46–60 ☐ 61 and above
4. Location (Village/LGA/State): ___________________________
5. Highest Educational Qualification:
   ☐ No formal education ☐ Primary ☐ Secondary ☐ Tertiary
6. Primary Occupation:
   ☐ Farming ☐ Trading ☐ Other (please specify): _______________
7. Are you a direct beneficiary of the MCRP-distributed solar pump?
   ☐ Yes ☐ No
8. When did you receive the solar pump?
   ☐ Less than 6 months ago
   ☐ 6 months – 1 year ago
   ☐ Over 1 year ago
9. What type of crops do you cultivate using the solar irrigation system? (Tick all that apply)
   ☐ Rice ☐ Maize ☐ Vegetables ☐ Fruits ☐ Others (specify): _______________

Section B: Agricultural Productivity and Cropping Intensity *(Objective 1)*

4. How many farming cycles did you complete **before** receiving the solar pump annually?
   ☐ 1 cycle ☐ 2 cycles ☐ 3 or more cycles
5. How many farming cycles are you completing **now** with the solar pump?
   ☐ 1 cycle ☐ 2 cycles ☐ 3 or more cycles
6. Has the yield per hectare improved since adopting the solar pump?
   ☐ Yes ☐ No
   If Yes, by approximately how much?
   ☐ <10% ☐ 10–30% ☐ 31–50% ☐ >50%
7. Have you diversified into new crops since using solar irrigation?
   ☐ Yes ☐ No
   If Yes, which ones? ___________________________
8. Rate the overall improvement in your agricultural productivity since using the solar pump:
   ☐ No improvement ☐ Slight ☐ Moderate ☐ High ☐ Very High

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Section C: Fossil Fuel Reduction and GHG Emissions ***(Objective 2)***

9. What type of irrigation system did you use **before** receiving the solar pump?
☐ Diesel pump ☐ Manual (e.g., watering cans) ☐ None

10. On average, how many liters of diesel did you use per month before receiving the solar pump?
☐ Less than 20L ☐ 20–50L ☐ More than 50L

11. Are you still using diesel-powered irrigation?
☐ Yes ☐ No
If Yes, how frequently? ☐ Always ☐ Occasionally ☐ Rarely

12. Do you think solar irrigation has reduced your farm's carbon footprint (GHG emissions)?
☐ Yes ☐ No ☐ Not Sure

13. In your opinion, how environmentally friendly is the solar pump?
☐ Not at all ☐ Slightly ☐ Moderately ☐ Very ☐ Extremely

Section D: Economic Impact of Solar Pump Usage ***(Objective 3)***

14. What was your average monthly energy (diesel/fuel) cost for irrigation **before** receiving the solar pump?
₦ _______________

15. What is your average monthly energy cost for irrigation **now** (with solar pump)?
₦ _______________

16. Has your overall income from farming changed since using the solar pump?
☐ Increased ☐ Decreased ☐ No change

17. If your income has increased, estimate the percentage increase:
☐ <10% ☐ 10–30% ☐ 31–50% ☐ >50%

18. Has the time and labor required for irrigation changed since using the solar pump?
☐ Increased ☐ Decreased ☐ No change

Section E: Challenges and Barriers to Usage ***(Objective 4)***

19. Have you experienced any **technical issues** with the solar pump?
☐ Yes ☐ No
If Yes, specify: ____

20. Do you have access to repair and maintenance services for the pump?
☐ Yes ☐ No ☐ Not Sure

21. Have you received training on the use and maintenance of the solar pump?
☐ Yes ☐ No

22. Do you think there is sufficient community or institutional support for solar pump users?
☐ Yes ☐ No ☐ Not Sure
If No, what support is lacking? ___________________________

23. What major challenges have you encountered? (Tick all that apply)
☐ Technical faults

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☐ Lack of spare parts
☐ Poor access to water
☐ Lack of training
☐ Vandalism/theft
☐ Others: ____________________

Section F: Recommendations and Future Needs *(Objective 5)*

24. Do you think solar irrigation should be scaled up to other farmers in your area?
☐ Yes ☐ No

25. What improvements would you recommend to enhance the solar irrigation intervention?
☐ Better training
☐ Local spare parts availability
☐ Financial support
☐ Government subsidy
☐ Improved access to water
☐ Others: ________________________

26. What support would make the system more sustainable in the long term?