World Vegetable Center

Feed the Future Innovation Lab for Small Scale Irrigation (ILSSI)

Study protocol

Drivers and impacts of the adoption of solar-powered pumps for irrigation by vegetable producers in Mali

June 2022

BASIC PROJECT INFORMATION

Source of funding/donor:	ILSSI
Project period:	April to June 2022
Study country/countries:	Mali
Type of study:	Quasi-experimental study (Propensity score matching – PSM)
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Consultants:	-
International research partners:	Research partners under the ILSSI project
Local research partners:	-

OUTLINE

1. RESEARCH BACKGROUND

In sub-Saharan Africa, just 6% of the area of cultivated farmland is irrigated (You et al., 2010). Low use of irrigation is one of the key constraints to raising agricultural productivity in general, and vegetable production in particular. Climate change is further increasing the importance of efficient irrigation systems. Smallholder farmers are often constrained in their ability to invest in irrigation equipment and lack skills to use and maintain the equipment after installation. Other constraints include the poor organization of irrigation water users, the drop in water levels in the reservoirs, and the poor management and lack of maintenance of the facilities (Millogo et al., 2021).

Several irrigation systems are available, including man-powered, gravity and electricity (fuel, solar, etc.) based systems. Each system has its strengths and weaknesses. Solar-based irrigation systems have received much interests over the past decade. Xie et al. (2021) and Lefore et al. (2021) explained that solar photovoltaic is a promising alternative for irrigation development in Africa. Solar-based irrigation systems are climate-smart solutions that can facilitate smallholder access to irrigated agriculture and strengthen productivity to achieve the Sustainable Development Goals of zero poverty and hunger (Terlau, 2018). These solutions can provide reliable, cost-effective and environmentally sustainable energy for decentralized irrigation services that can improve livelihoods (productivity, income, food security), increase social welfare (poverty alleviation, emissions reduction) and reduce spending on fossil fuels (IRENA, 2016). Solar-powered irrigation systems are low-cost options that can contribute to climate mitigation and adaptation (Rahman et al., 2022). Solar pumps are also increasingly available in West Africa (e.g., Ghana, Senegal, Mali, The Gambia) and there is an increasing number of private sector solar pump equipment suppliers (Brunet et al., 2018; Lefore et al., 2021; Lewis-Swan et al., 2019). Despite this, there is limited evidence to our knowledge on the drivers of adoption and the impact of solar pumps for irrigation among smallholder farmers in general and vegetable producers in particular. Most existing studies are for Asia.

According to Bastakoti et al. (2020), the high capital cost of the technology remains the biggest barrier to the adoption of solar-powered irrigation pumps in India. The introduction of lower costs pumps, could relax budget constraints. Analyzing the determinants of farmers' decision to adopt solar powered pumps in northern Bangladesh, (Sunny et al., 2022) reported that farming experience, knowledge, environmental awareness, soil fertility, and irrigation machinery ownership significantly promoted adoption. Farmers who adopted solar powered pumps were able to minimize irrigation costs. (Kumar et al., 2020) also explored the determinants of farmers' decision to adopt solar powered pumps in India and highlighted that perceived benefit, perceived compatibility and government incentives have a significant impact on the intention to use solar powered pumps, whereas high investment cost and lack of awareness regarding government subsidies are the main reason for non-adoption. Using a structural equation model, (Zhou and Abdullah, 2017) showed that predictors of solar water pump technology usage in Pakistan were gender, age, education awareness, cost tolerance, facilitating conditions, perceived ease of use and usefulness.

In Mali, a West African country, vegetable production has increased rapidly over the past decades. Most vegetable producers continue to rely on rainwater, watering cans and buckets for irrigation (Stauffer and Spuhler, 2020). This type of irrigation is labor-intensive and time consuming, while the use of motorized pumps could boost farmers' incomes, improve their health and resilience, and increase food supplies. According to Kergna et al. (2018) there are opportunities to adopt and scale-up small-scale irrigation in Mali, but farmers typically choose irrigation systems based on cost, management and revenues. Kane et al. (2018) showed that use of manual irrigation in Mali is not economically viable for the production of potatoes, shallots, and tomatoes as the benefit-cost ratio is below unity whereas the California system, drip and sprinkler all have a benefit-cost ratio above unity. There is a general consensus that small-scale irrigation can improve farm performance in Mali but adoption of solar powered pumps remains low. While there is a growing market for solar pump equipment, there is a paucity of information that can help to promote increased adoption. Also, sound evidence of the impact of solar-powered irrigation among vegetable farmers is important to guide future investment. Against this backdrop and within the framework of the USAID Feed the Future Innovation Lab for Small Scale Irrigation (ILSSI), this study will assess both the drivers and the impact of the adoption of solar-powered irrigation among vegetable producers in Mali.

2. RESEARCH OBJECTIVES

The overall objective to analyze the economics of the adoption of solar-powered pumps for irrigated vegetable production in Mali. Specifically, the study will:

- Analyze the socio-economic drivers of the adoption of solar-powered pumps in irrigated vegetable production;
- Analyze the impact of adopting solar-powered pumps in vegetable production on the household (both male and female) labor costs, crops yields, length of production period, household income and frequency of nutrient-rich foods (vegetables, legumes, meat, dairy) consumption.

3. RESEARCH HYPOTHESES

Based on the specific research objectives, the following hypotheses will be tested:

- Experience in agriculture, household wealth, and access to credit are positively associated with the adoption of solar-powered pumps in irrigated vegetable production;
- Farmers who adopt solar-powered pumps for irrigated vegetable production spent less (both male and female) labor than non-adopter farmers;

- Farmers adopting solar-powered pumps in irrigated vegetable production obtain a higher crop yield than non-adopters;
- Farmers who adopt solar-powered pumps for irrigated vegetable production have longer production period;
- Farmers who adopt solar-powered pumps for irrigated vegetable production have higher crop income than non-adopters.
- Farmers who adopt solar-powered pumps for irrigated vegetable production have higher frequency of nutrient-rich foods (vegetables, legumes, meat, dairy) consumption than non-adopters.

4. METHODOLOGY

4.1. Intervention

We define our intervention as the use of solar-powered pump for vegetable production and the present study analyzes the adoption of these pumps. Adoption here is defined as the current use of a solar-powered pump to produce vegetables. We will focus on farmers who have used solar-powered pumps during the last 12 months. We will only focus on farmers who reported that they use solar-powered pump over the specified time frame and use them as our treatment group. We acknowledge that there are differences in the quality of pumps used and we will explore this in the analysis.

4.2. Theory of Change (ToC)

Farmers adopting solar-powered irrigation are expected to save costs of water and labor, and possibly fuel if solar-powered pumps replace diesel-powered pumps. If solar-powered pumps replace manual water carrying than this may especially save women’s labor time. The freed-up labor time can be used for other domestic tasks or income-earning activities. It is also possible that the more efficient use of water and labor facilitates a more intensive use of agricultural land that contributes to greater farm earnings. As irrigation reduces the risk of uncertain rainfall, the production period can be extended so that farmers can grow crops for a longer period. With all this, farmers adopting solar-powered pumps are likely to record higher productivity and higher income as well as a more stable income. All this can contribute to increase the consumption of nutrient-rich foods (vegetables, legumes, meat, dairy).

4.3. Study area

We will conduct the study in Mali which is a country of focus for the ILSSI project. The geographical scope of the study will cover peri-urban vegetable production sites around the cities of Bamako, Kayes to Kidal via Koulikoro, Sikasso, Ségou, Mopti, Timbuktu and Gao. The final list of cities will be discussed with extension officers and also take into account security issues in the country.

4.4. Quantitative evaluation approach

Our quantitative evaluation approach relies on a quasi-experimental design using Propensity Score Matching (PSM). This design was selected to account for the fact that adoption of solar-powered pumps is not random and most likely determined by the socio-economic characteristics of the farmers as well as market access and biophysical conditions such as access to a water source. PSM helps to reduce the selection bias that may be present in non-experimental data. We will estimate a propensity score as a probability that a farmer adopts a solar-powered pump by using farmers observed characteristics (age, education, assets, access to credit, market access, biophysical conditions).[1] Adopter and non-adopter will then be matched based on the propensity score.

- **Definition of main outcome of interests**

Table 1 summarizes the key outcome variables of interests and the measurement approach:

Indicator		**Measurement**	**Unit**
Labor	Total aggregated labor (Household and paid)	Calculated sum or reported expenses on paid labor for farming activities and imputed cost of household labor	USD/ha
	Household labor	Calculated household labor based on reported number of household members engaged in farming activities and time spent by them	Man.Day/ha
	Total household female members labor	Calculated female household member labor based on reported number of female household members engaged in farming activities and time spent by them	Man.Day/ha
Yield	Aggregated yield	Calculated based on reported total output with the imputed price of each crop divided by the and acreage	USD/ha
Production period	Length of the production period	Number of months of the production period	Months
Income	Crop income	Calculated based on reported amount of money obtain from sales of outputs	USD
Frequency of nutrient-rich foods (vegetables, legumes, meat, dairy)	Food (consumption) frequency	# of times the respondents reported that he/she ate nutrient-rich foods (vegetables, legumes, meat, dairy per year	# per year

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[1] We will organize some group discussion with equipment suppliers to get a better sense of the profiles of farmers adapting solar-powered pumps. See more details under the qualitative evaluation approach.

Data and data collection

Following the specific research objectives, we will collect primary data on the respondents' characteristics as well as outcomes such as labor use, crop yield and household income. In practice, we will conduct a single survey after creating a sample list of farmers. The list will be used to categorize farmers as adopters (have used a solar-powered pump for at least 1 year, still owns and uses a functional solar-powered pump) and non-adopters (do not meet the definition of adopters). The non-adopter group might use manual irrigation methods, diesel-powered pumps or other methods. Data will be collected through structured and semi-structured interviews with a sample of vegetable farmers. Data collection instruments will be digitalized in KoBoToolbox and this will allow us to use a Computer Assisted Personal Interview method by using tablets for data collection. We will rely on highly-qualified enumerators who also understand local languages to collect data. Enumerators will undergo a training on the survey instruments. Before starting each survey, the enumerator is responsible to read and document the consent of the respondent. Data quality will be ensured through back checks and high frequency checks by the research team.

Sampling

Power calculations were done using Optimal Design Plus by estimating the Minimum Detectable Effect (MDE) that we can measure as far as changes in labor allocation, yield and income are concerned and given a power of 80%. We considered the following assumptions:

Table 2: Assumptions used for the power calculations

Item	Assumption	Justification
Alpha	0.05	Default value
Beta (power)	80%	Default value

Figure 1 illustrates the results of the power calculations:

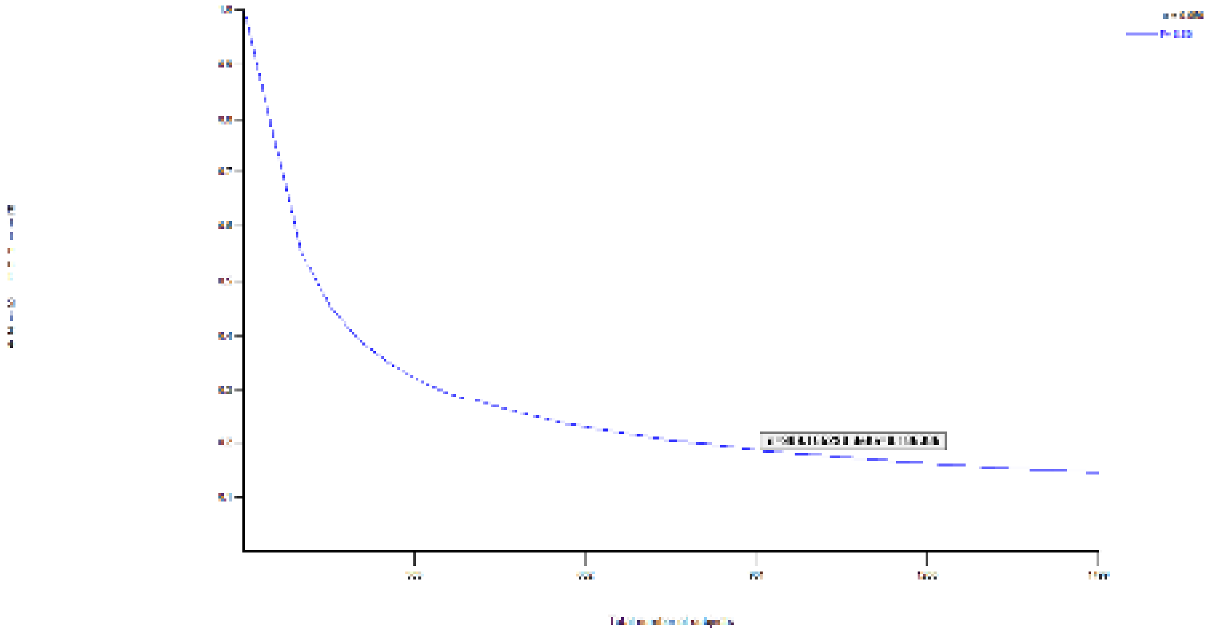

Figure 1: Graphical representation of the power calculations in Optimal Design Plus

A sample of 900 vegetable farmers can detect a small to medium effect size (about 0.18^{2}) with 80% power. Considering that we will be using a PSM methods, we will oversample the control group to ensure sufficient overlap with the intervention group. In practice, participants will be identified and approached through engagement with the leadership of existing farmer-based cooperatives or associations. This identification will take the form of an enumeration of vegetable farmers. The enumeration will allow us to collect basic information on farmers irrigation methods to construct our sample frame. Farmers will be assigned to groups based on their current use of solar irrigation for vegetable production and survey participants will be selected randomly from each group.

- **Data analysis**

In practice, we will follow a four-step process: estimating the probability of participation, i.e., the propensity score; selecting a matching algorithm that is used to match adopter with non-adopter in order to construct a comparison group; checking for balance in the characteristics of the treatment and comparison groups; and estimating the program effect and interpreting the results.

    - Estimating the Propensity Score: The propensity scores will be constructed using a probit regression to estimate propensity score. It is important to note that characteristics

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[2] With the mean and standard deviation of each outcome variable we can estimate the actual minimum detectable effects.

which may have been affected by the treatment are not included. This analysis will also shed light on the drivers of solar-powered pump adoption.

- Select a Matching Algorithm: We will use the nearest-neighbor matching algorithm to match each adopter to the non-adopter with the closest propensity score.
- Check for Balance: Once farmers are matched, the characteristics of the constructed treatment and comparison groups should not be significantly different. We will use t-test to compare the means of all covariates included in the propensity score in order to determine if the means are statistically similar in the treatment and comparison groups.
- Estimating the impact of solar-powered pump adoption: Following the estimation of propensity scores, the implementation of a matching algorithm, and the achievement of balance, the intervention's impact may be estimated by averaging the differences in outcome between each adopter and its neighbor no adopter. We will rely on the following specification:

$$Y_i = \alpha + \beta T_i + Z + e_i \qquad \text{[Eq. 1]}$$

where Y_i is the outcome variable of interest, T_i a dummy variable that takes the value of 1 if the farmer uses a solar-powered pump or 0 otherwise; Z is a set of co-variates that can affect the variable of interest, and e is the error term. Depending on the structure of the sample, we will control for cities fixed-effects.

To implement the PSM analysis, we will use the *psmatch2* command in STATA

4.5. Qualitative evaluation approach

In parallel with the quantitative component, the qualitative component of the impact evaluation will be used to understand the processes underlying the changes that can be attributed to the intervention against the ToC.

- **Data**

Before the quantitative survey, we will discuss with local irrigation suppliers to get a better sense of the profiles of farmers adopting solar-powered pumps. Data on expectations and experiences with the intervention will be collected from the adopters group. Qualitative data collection will be conducted through Focus Group Discussions (FDGs) and In-Depth Interviews (IDI) with key informants along with the baseline survey and after the endline survey.

One FDG will be organized with farmers using solar powered pumps and another one will be organized with farmers not using solar powered pumps. Each FGD will involve up to 7 participants, including both male and female farmers. Key questions to discuss through the FGDs are: What are:

- Are solar-powered pumps available and easy to access (equipment, information, etc.)?
- How/why do farmers make the decision to adopt purchase solar-powered pumps? (Question for users only)

- How do solar-powered pumps compare with other irrigation systems? (Question for users only)
- What has been the experience (perception on the technology, usefulness, benefices, constraints, etc.) with using purchase solar-powered pumps? (Question for users only)
- What are the reasons for not using solar-powered pumps? (Questions for non-users only)
- How can solar-powered pumps be made more accessible for farmers?

Up to 5 IDIs will be organized with solar-pump suppliers. This will include both official registered and non-registered solar-pump suppliers. Key questions to discuss through the qualitative evaluation are:

- Who are the key players on the solar-powered pumps market?
- Who are the farmers who purchase solar-powered pumps?
- What are the constraints related to the use/supply of solar-powered pumps?
- How can solar-powered pumps be made more accessible?

- **Sampling**

Purposive sampling methods will be used to identify some solar-powered pump adopters for case studies. The saturation methods will be used to determine the sample size.

- **Data analysis**

Qualitative data will be analyzed by using tools such as content analysis.

4.6. Ethical considerations

This study will follow the ethics guidelines as formulated by the WorldVeg Institutional Biosafety and Research Ethics Committee (IBREC). Participants will be informed how we will use and store data and receive confirmation that no data will be shared with third parties that would enable these parties to identify the respondents. Personal data can only be collected after a research participant has given explicit consent to record these data. Only the minimum number of personal identifiers necessary to conduct the surveys will be collected. Caution will be taken not to collect data that could pose any harm to respondents should these be disclosed, such as political orientation, personal wealth, ethnicity and religion.

We will further submit the protocol to the Institutional Review Board of Texas A&M University. We will adopt a prospective registration strategy by recording and publishing specific information about our evaluation plan up front, before data are collected or the impacts assessed. In this respect, we will register our study in the Registry for International Development Impact Evaluations (RIDIE). Finally, we will develop a Pre-Analysis Plan prior to collecting the baseline data.

To limit the Covid-19 pandemic risks, masks and gels for handwashing will be provided to enumerators. All the nationally-imposed Covid-19 restrictions will be observed, including undertaking strictly socially distanced interviews (outdoors in covered but well-ventilated areas, with masks, and no physical contact). Additional precautions to manage the possible risk of Covid-19 will be observed as follow:

1) The enumerator should record the following on a daily basis before going to interview the study participants.
    a. Does he/she have fever, cough, body ache, fatigue
    b. Are his/her close contacts (family member, friends) being sick with the above symptoms or tested positive for Covid-19
2) Before starting the interview, the enumerator checks with the teachers, schoolchildren and any respondents on the above two aspects.
    a. If the answers for any of the above questions is "YES" the enumerator should report to the project supervisor and seek further guidance.
    b. If it is noticed that someone in the staff is not feeling well or have some suspected symptoms, interviews will be avoided until he will be tested or he will be recovered.
3) Interviews scheduled during local outbreaks, or with people found to be infected, will of course be canceled or postponed.

5. LOGISTICS

Table 1 presents the anticipated timeline of the study.

Table 1: Timeline

Activity	April	May	June	Julliet	August	Sept	Oct	Nov	Dec
Development of the study CN	🟧								
IRB and other required approvals Registration of the study		🟧							
Development of survey instruments (Including Pretest)		🟧							
Hiring and training of enumerators/field staff			🟧						
Census + Data collection				🟧	🟧				
Data cleaning and primary analysis					🟧	🟧			
Analysis						🟧	🟧	🟧	
Reporting							🟧	🟧	
Submit the paper of journal publication								🟧	🟧

6. BUDGET

Please refer to the attached excel sheet.

7. REFERENCES

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