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Solar powered Irrigation System in Tabuk City Kalinga and Quezon-mallig, Isabela:Economic Contribution, Challenges, and Sustainability, Philippines

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Abstract— *This study assessed the impact, usability, and sustainability of the Solar-Powered Irrigation System (SPIS) among 33 farmers in Tabuk City, Kalinga, and Quezon-Mallig, Isabela. Using a quantitative descriptive design, the research found that SPIS significantly improved crop yield, quality, and farm income, while reducing irrigation and energy costs. Most respondents were male, aged 51–60, with modest incomes and limited formal education, highlighting the need for targeted training. Land ownership was high, and crop farming dominated, but many previously relied on costly diesel pumps or rainfed agriculture. While SPIS was rated highly for energy efficiency and integration with existing infrastructure, moderate ratings for ease of use, system reliability, and low scores for training and technical support revealed operational gaps. Institutional and community support was strong, with widespread willingness to recommend SPIS and confidence in government investment. The study concludes that SPIS offers substantial benefits for smallholder farmers but recommends enhanced technical training, local support hubs, improved financial access, infrastructure upgrades, stronger policy support, and greater community engagement to ensure long-term sustainability and equitable access.*

Keywords— ***utilization of the SPIS, economic contribution of the SPIS, Solar-Powered Irrigation System (SPIS), SPIS implementation sustainability plan***

I. INTRODUCTION

Farming is a key source of income in the Philippines, especially in rural areas, and irrigation is vital for crop production. However, rising food demand, limited freshwater, high energy costs, and unreliable electricity make traditional irrigation challenging and environmentally harmful due to greenhouse gas emissions and pollution.

Solar-powered irrigation offers a promising alternative by using photovoltaic (PV) technology to convert sunlight into electricity for water pumps. Case studies worldwide including India, Jordan, the US, Pakistan, China, and the Philippines show that solar irrigation improves water access, reduces costs and emissions, and increases farmers' income1. In the Philippines, solar-powered irrigation has led to significant diesel savings and high returns on investment, while also supporting gender empowerment and water access in remote areas.

The Philippine government, through the Department of Agriculture and National Irrigation Administration (NIA), has promoted solar irrigation since 2018. By the end of 2023, 82 solar-powered pump projects were completed, benefiting over 1,000 farmers and irrigating 866 hectares nationwide. In the Cordillera region, 21 projects were completed in 2023, serving 253 hectares and 365 farmers.

Despite these advances, research on the sustainability and economic impact of solar-powered irrigation in Kalinga and Isabela remains limited. This study aims to fill that gap by assessing how these systems have affected farmers' income, costs, and crop yields in Tabuk City, Kalinga, and

Quezon-Mallig, Isabela from 2022 to 2024, to inform future agricultural development.

1.1. Conceptual Framework

The study aims to explore the perceive economic impact of the Solar-Powered Irrigation System (SPIS) within the coverage areas of Upper Chico River Irrigation System (UCRIS), particularly in Tabuk City, Kalinga, and Quezon-Mallig, Isabela for the years 2022 to 2024. The framework outlines how the adoption of SPIS, as a sustainable solution to water shortages in non-operational areas of UCRIS, can lead to improvements in agricultural productivity, income generation, and overall economic development of beneficiaries.

The framework below highlights the role of SPIS as an innovative and sustainable solution to help farmers in irrigation of their crops without relying on expensive and unreliable fuel-electricity powered systems. Through the improvement of access to irrigation water by renewable energy, SPIS is expected to contribute in increasing crop production, reduced operational costs and enhanced livelihoods for farmers. The conceptual framework also serves as a guide for analyzing how government-supported technological innovations in agriculture, like SPIS can address rural irrigation problems and provide contribution to sustainable economic growth in farming communities.

1.2 Statement of the Objectives

This study aimed to examine the Solar-Powered Irrigation System (SPIS) as implemented for beneficiaries within the coverage of the Upper Chico River Irrigation System in Tabuk City, Kalinga, and Quezon-Mallig, Isabela for the years 2022–2024. Specifically, this aimed to:

1. assess the perceived economic contribution of the SPIS towards beneficiaries;
2. identify challenges and issues in the utilization of the SPIS; and
3. propose a sustainability plan addressing the identified challenges in SPIS implementation.

II. REVIEW OF RELATED LITERATURE

This chapter presents the related literature and studies after the thorough and in-depth search by the researcher. This will also present the local and global studies on the Improvement of Water Use Efficiency of Irrigation System integrating modernization.

Solar-powered irrigation systems have been widely recognized for their potential to support sustainable agriculture. According to the International Renewable Energy Agency (IRENA, 2016), these systems reduce greenhouse gas emissions by replacing diesel or electric pumps with clean and renewable energy. The Food and Agriculture Organization (FAO, 2018) also supports this view by highlighting how solar irrigation can address water scarcity and reduce operational costs for smallholder farmers.

The first solar pumps were installed in the late 1970s. Since then, Photovoltaic (PV) water pumping systems have shown significant advancements. The first-generation PV pumping systems used centrifugal pumps, usually driven by DC motors or variable frequency AC motors, with proven long-term reliability and hydraulic efficiency varying from 25 percent to 35 percent. The second-generation PV pumping systems introduced positive displacement pumps, progressive cavity pumps and diaphragm pumps for smaller water quantities, generally characterized by lower PV input power requirements, lower capital costs and higher hydraulic efficiencies (Chandel, 2015). This pioneering work was piloted in different countries around the world. Moreover, it was also stated that apart from the environmental advantages, the economic benefits of solar irrigation are long-term. Although initial costs are high, the reduction in fuel and electricity bills makes the investment worthwhile over time.

Vicente (2024), a solar energy expert from Sunhero, explains how solar panels can be a practical and sustainable solution for agricultural irrigation. According to him, using solar-powered systems allows farmers to pump water for their crops without relying on electricity from the grid or costly diesel fuel. This helps reduce farming expenses and protects farmers from rising fuel prices and power interruptions. The author also points out that solar irrigation systems are especially useful in areas with abundant sunlight, as they can run efficiently throughout the day. One of the main benefits is energy independence where farmers can irrigate their land without worrying about electric bills or fuel availability. Since these systems do not release harmful emissions, they are environmentally friendly which makes them a clean alternative to traditional pumps. Moreover, the author highlights that although the initial setup cost can be high, around €1,000 to €1,500 per kilowatt, the long-term savings make it a smart investment. In addition, solar-powered systems can be customized to match the size of the farm, the type of crops, and the amount of water needed. They can also be combined with existing irrigation systems, making the switch to solar easier and more flexible. Overall, solar panels offer farmers a reliable and cost-effective way to irrigate their fields while promoting sustainable agriculture.

In 2019, World Bank reported how solar-powered irrigation systems can greatly help farmers, especially in places where electricity is limited. In some parts of Sub-Saharan Africa, using solar pumps helped farmers grow more crops, sometimes up to more than 50%. This means farmers could earn more money and have a better quality of life. Solar irrigation works well in rural areas because it uses the sun's energy to power water pumps, removing the need for diesel or electricity from the grid. However, many small farmers cannot afford to buy these systems because they cost too much at the start. The World Bank suggested that governments and private companies should work together to give support, like loans or discounts, to help farmers get these systems. If more farmers can use solar pumps, it would not only improve farming but also make it more eco-friendly and help feed more people.

Furthermore, the International Water Management Institute (2020) shared that combining solar power with smart irrigation tools like soil moisture sensors can make farming even more efficient. These tools help farmers know exactly when their crops need water and how much, so they don't use more water than necessary. This prevents overwatering, which not only saves water but also protects the soil and crops. By using solar energy to run these smart systems, farmers can save both water and electricity. This approach is very useful in places where water is limited or where farmers rely on expensive fuel or electricity. The IWMI highlighted that this kind of system can make farming more sustainable in the long run, because it helps manage water better, lowers costs, and supports environmentally friendly practices.

A study by Fawzi et al., (2022) developed a fully automated, solar-powered irrigation system designed to help farmers in remote areas manage water use efficiently. The main objective of the study was to create a sustainable irrigation setup that will reduce water waste, using solar energy as a power source, and provides remote monitoring through GSM (Global System for Mobile Communication) alerts. The system included a DC water pump powered by solar panels, soil moisture sensors to control water flow automatically, and an ultrasonic sensor to check the water level in the reservoir. It also had a GSM module that sent text alerts about the battery level and water status. The irrigation system was programmed to stop working if the battery charge dropped to 10% or if the water level in the reservoir went below 10 cm, ensuring safe and efficient operation. Based on tests, the system worked well in areas without access to electricity, showing that it can support water-saving farming practices in places with limited resources and frequent droughts.

The study by Akter and Mitu (2024) investigates the economic viability and social acceptability of solar-powered irrigation systems (SPIS) in Bogra, Bangladesh. Recognizing agriculture's pivotal role in the nation's economy, the researchers aimed to explore sustainable irrigation methods that could alleviate water scarcity and reduce reliance on non-renewable energy sources. Their methodology encompassed field surveys, interviews with local farmers, and analysis of existing SPIS implementations to assess both economic outcomes and community perceptions. Findings revealed that cultivating high-value crops, such as summer tomatoes and hybrid vegetables, significantly enhanced the profitability of SPIS. However, the initial costs of installation posed challenges for widespread adoption. To address this, the study recommends strategies like government subsidies, localized manufacturing to reduce equipment costs, and collaborative models where small-scale farmers share resources. Moreover, enhancing awareness through training programs and showcasing successful case studies were identified as crucial for improving social acceptance. The research underscores that with appropriate economic incentives and community engagement, SPIS can be a sustainable solution for Bangladesh's agricultural sector.

Research introduced a practical and affordable idea for a solar-powered smart irrigation system designed for small- and medium-sized farms. His goal was to help farmers use water more efficiently while also saving on energy costs. The system is controlled by a mobile phone and runs on solar power, making it especially useful for areas without easy access to electricity. Sahin detailed the basic parts of the system, how they are connected, and their estimated costs. He then compared this smart setup with traditional irrigation methods like drip, sprinkler, and pivot systems. The results showed that while the smart system might cost more at the start, it saves a lot of water and energy in the long run. It also offers better environmental benefits and can help increase crop production. Overall, the study suggests that switching to modern irrigation systems like this one could make a big difference not just for individual farmers, but also for the country's economy by promoting more sustainable farming practices (Sahin, 2024).

Similarly, Wanyama et al. (2023) developed an innovative solar-powered smart irrigation system, known as the Smart Irri-Kit, designed to help smallholder farmers in developing countries optimize irrigation practices. With the challenges posed by climate change and the labor-intensive nature of traditional irrigation, many farmers struggle to maintain efficient watering schedules. The Smart Irri-Kit addresses these issues by automating the irrigation process based on real-time feedback from soil moisture sensors. The system is powered by solar energy, which makes it suitable for areas with unreliable electricity. It includes a water tank level control system that triggers the irrigation pump when needed, ensuring water is delivered only when the soil moisture drops to predetermine levels. The system was tested at Makerere University Agricultural Research Station and showed reliable performance, with the soil moisture sensors' readings aligning closely with traditional gravimetric methods. This system not only conserves water but also reduces operational costs by using renewable energy. The researchers suggest that the Smart Irri-Kit could significantly improve agricultural productivity and sustainability by automating water delivery and making irrigation more efficient. Future developments could integrate weather data and remote monitoring features to further enhance its functionality.

Schnetzer and Pluschke (2017) conducted a study to explore the benefits of Solar-Powered Irrigation Systems (SPIS) in reducing greenhouse gas emissions and promoting energy independence, particularly in remote areas. Their objective was to assess how SPIS could replace traditional fossil fuel-powered pumps with solar energy to reduce emissions and provide reliable energy for irrigation, especially in areas without electricity grids. The methodology included a life cycle assessment (LCA) to evaluate the emissions of SPIS compared to diesel and grid-powered systems. The findings revealed that SPIS could reduce greenhouse gas emissions by up to 97-98% compared to diesel pumps and 95-97% compared to grid-powered pumps. Additionally, SPIS can provide energy independence in off-grid areas and help mitigate water stress during dry seasons. This shift also frees up time for farmers, allowing them to engage in other productive activities, thus improving overall farm productivity.

Researchers demonstrates that Solar-Powered Irrigation Systems (SPIS) can significantly improve agricultural productivity by increasing access to water, allowing farmers to grow more diverse crops, including vegetables during dry seasons. This enhanced production can lead to increased income from selling surplus produce and improve food security, particularly for small-scale farmers. However, the adoption of SPIS faces challenges, primarily due to the high initial investment cost and the lack of suitable funding schemes. Despite its proven technical viability and attractive return on investment, solar pumps are often used only for a limited time each year, typically during a single crop harvest. The study suggests that using the energy generated during off-seasons could enhance the economic performance of SPIS. To address funding challenges, various financial models, such as community-based investment, Energy Service Companies (ESCO), micro-leasing, and shared liability models, can help farmers access the capital needed for installation. Group-based systems are particularly effective in reducing individual costs and risks, promoting shared benefits, and encouraging knowledge exchange, which can lead to more widespread adoption of SPIS among poor farmers (Ould-Amroche et al. 2010, Burney et al. 2009).

Economic viability and attractiveness to farmers is often compromised by subsidies for liquid fuels or grid electricity (Ould-Amroche 2010). In such cases a reform of subsidy policies could create the needed incentives for the adoption of SPIS. Reducing subsidies, however, bears the risk to affect the poorest farm households most, hence political will and risk-taking for such reforms is generally low. Further challenges lie in the lack of skilled personnel for the design, installation and maintenance of SPIS and the lack of codes and standards. Promotion of SPIS should therefore comprise support to the development capacities and business opportunities in the supply chains and a sound legal framework.

The study by Ramli R. M. and Jabbar W. A. (2022) focused on designing and implementing a solar-powered irrigation system with IoT capabilities, specifically for the simultaneous operation of multiple irrigation areas using standalone solar pumps. The system utilizes a model based on linear programming to optimize water distribution, taking into account the required water volume and solar power generated by photovoltaic (PV) panels. The results demonstrated that operating multiple PV-based pumps simultaneously improved efficiency and saved energy compared to individual pump operation. In a similar vein, another study on an "IoT-solar energy powered smart farm irrigation system" aimed to develop an IoT-based solar water pumping system that operates based on soil moisture, temperature, and humidity. This system incorporates a fuzzy-based algorithm for automatic control of the pump and supports both manual and remote operation. The use of IoT technology allows for more precise irrigation control, ensuring optimal water usage while also enhancing the system's adaptability to varying environmental conditions. Both studies highlight the potential of solar-powered, IoT-enabled irrigation systems to increase efficiency, reduce energy consumption, and improve agricultural productivity.

Reghukumar A. (2019) highlighted the design and implementation of a water pumping system based on the health of plants. The system model supports the automatic start/stop of the electric motor based on water threshold values. The study analyzed the sensor data to decide on irrigation time according to plant health status with the plant's threshold value. An emergency notification about plant health will be sent to the farmer via email over the IoT platform when needed. The farmer also can access information regarding to soil and environment parameters including soil pH value and moisture, temperature and flame values through Graphical User Interface (GUI) to decide whether the plants need to be irrigated.

Farmers in Bihar, India, were able to switch from deficit to full irrigation after introduction of SPIS, resulting in improved plant health, increased crop yields and extra income from marketing the excess produce (GIZ 2013). In Maharashtra, India, the replacement of diesel pumps by SPIS helped to improve the on-farm economic benefits. These were in part attributed to micro irrigation practices integrated with SPIS, allowing to reduce input costs, increase productivity, and generate greater income from higher yields (Honrao 2015). In the Sudano-Sahel area of Northern Benin, SPIS (with low-pressure drip irrigation) were installed in vegetable gardens formerly watered with cans and hauled water. This allowed the women farmers to become net producers of vegetables, generate income from market sales, and substantially increase their household nutrition intake and food security (Burney et al. 2009). The development of sound business models ensures that improvements in agricultural productivity will translate into greater income and financial sustainability (see Powering Agriculture Programme1). In Jordan, for instance, ECO Consult is supporting commercial farms to retrofit multi-span greenhouses with hydroponic technologies and photovoltaic panels to generate enough power to operate the lighting, pumping, and air moderation systems. This allows them to achieve resource use efficiency goals and to make the technology commercially attractive.

It is important to note that SPIS bears the risk of fostering over-exploitation of water resources, if not adequately regulated. Once SPIS is installed, there is no cost per unit of power and, thus, no financial incentive for farmers to save on fuel/electricity for water pumping. Rather, there often is a financial incentive to intensify or expand production in order to pay off loans that were needed for the purchase of the SPI system. Thus, as SPIS might encourage improved production and increased food security, this would inadvertently lead to an increase in water consumption. Overall, this can lead to wasteful water use, over-abstraction of groundwater, and low field application efficiency (Shah and Kishore 2012, FAO 2017

Closas and Rap (2017) found that feasibility studies for SPIS commonly focus on technical and economic aspects but lack an assessment of the availability of and impact on water resources. An unforeseen drop of groundwater levels, however, may also have negative impacts on the profitability of a SPIS and its overall economic sustainability. Targeted subsidies could be linked to obligatory adoption of drip irrigation which, if properly operated, can increase the water use efficiency in the irrigated system. However, this does not necessarily reduce water abstraction or may even increase it as the “saved” water resources may be used to expand the irrigated area, add a cropping season, support a change in crops with different water requirements, or they may be sold to other farmers or water users (Ahmad et al., 2007; Benouniche et al., 2014).

The study by Raymund A. and Abhishek J. (2018) used an economic model to evaluate the financial outcomes for farmers, entrepreneurs, and the government under different irrigation pump scenarios, focusing on solar, electric, and diesel-powered pumps. Using a 15-year net present value (NPV) analysis, they compared capital and operating costs with revenues from water or electricity sales, assuming a 4% annual price increase due to inflation. Revenues from crop production were excluded, as they were assumed constant across options. The study found that electric pumps remained the cheapest option for farmers unless grid electricity subsidies were reduced, while government support for solar pumps became more favorable if solar system costs dropped by at least 20%. This would allow for higher government contributions toward solar pump costs while still saving public funds. Overall, the study emphasized that decreasing solar technology costs could make solar-powered pumps a more feasible and cost-effective alternative for both farmers and government programs.

In the Philippine context, solar irrigation is being promoted by the Department of Agriculture as part of its effort to modernize the farming sector. DA reports (2021) mention that solar-powered irrigation helps Filipino farmers reduce fuel dependency and cope with irregular rainfall patterns. The adoption of solar-powered irrigation systems (SPIS) in the country has been steadily increasing, driven by government initiatives aimed at modernizing agriculture and enhancing food security. As of early 2024, the Department of Agriculture (DA) has constructed over 200 SPIS units across the country, with plans to build between 500 and 1,000 additional units annually. Each unit is designed to irrigate between 8 to 30 hectares, depending on its size and capacity.

Additionally, National Irrigation Administration (NIA) has also intensified its efforts, completing 17 solar-powered irrigation projects by September 2023. These projects collectively provide irrigation to 830 hectares of agricultural land, benefiting 801 farmers and their families. For 2024, NIA has earmarked PHP 1.72 billion for 183 SPIS projects, aiming to irrigate an additional 2,168 hectares. Furthermore, a proposal for 791 more sites is under consideration, which could extend irrigation to 39,694 hectares nationwide. In a significant development, the Philippines inaugurated its largest solar-powered irrigation system in Isabela province in June 2024. This facility, equipped with over 1,000 solar panels that can irrigate 350 hectares and benefits approximately 237 farmers. Notably, this project is the first in the country to be constructed over an irrigation canal, preserving valuable farmland.

According to Sevilla (2022), solar-powered irrigation is particularly useful in areas without stable access to electricity, such as upland farms. It helps improve crop survival during dry months and enhances farmers' productivity. However, while solar irrigation systems are available in some provinces, their adoption is slow due to limited financial support. They emphasized the importance of public-private partnerships to promote wider use. (Garcia & Tolentino, 2021)

A report by the Bureau of Soils and Water Management (2020) shared that pilot solar irrigation projects in Northern Luzon have shown positive results, especially in rice and corn farming. These systems increased cropping intensity and reduced water loss. Moreover, Villanueva (2019) explained that aside from food production benefits, solar irrigation systems also contribute to rural development by generating job opportunities related to system installation and maintenance.

Furthermore, the study of Guno C.S. and Agaton C.B. (2022) analyzed solar irrigation systems in the Philippines using economic, environmental, and social methods to assess their feasibility for small-scale farmers. While solar systems have higher upfront costs compared to diesel pumps, they offer lower operational and maintenance expenses, leading to savings over time and reduced greenhouse gas emissions. The study found solar irrigation to be a good investment, with an average net present value of USD 4,517/ha, a 315% return on investment, and a payback period of 2.88 years, though actual results varied widely due to differences in land size and diesel use. About 69% of marginal farmers were interested in solar irrigation, but awareness of its environmental benefits remained low. To support adoption, the authors recommend more information campaigns, subsidies, and funding for research and development, as well as financial support for small-scale farmers and cooperatives. The study also noted that solar systems can store extra energy using batteries and water tanks, which enhances system reliability and allows surplus electricity to be used for other needs, especially in remote areas lacking consistent power supply.

On the other hand, Panganiban (2021), focused on understanding how useful and practical solar-powered irrigation systems are for farmers, especially those who don't have access to irrigation provided by the government. Many farmlands in the Ilocos Region, particularly in remote or less developed areas, struggle with low crop production because they lack proper irrigation. To help solve this, the government introduced the SPIS as a more environment-friendly and cost-saving option compared to traditional pumps powered by diesel or gasoline. The researcher looked into three actual SPIS sites located in San Nicolas and Piddig in Ilocos Norte, and San Jacinto in Pangasinan. To collect information, she visited these areas and interviewed farmers using a prepared questionnaire to know their experiences and opinions. She also measured how efficiently the water pumps were working. The results showed that the system worked quite well, with pump efficiency ranging from 49% to 69%, which means the pumps were able to deliver water effectively to the fields in most cases. The findings further revealed that solar-powered irrigation is a good solution for rice farms in the Ilocos Region. It helps farmers water their crops without relying on expensive fuel. However, the research also pointed out that there are areas in the system and in how the program is managed that could still be improved. These improvements would help make the system more reliable and beneficial for more farmers in the future.

Similarly, Escoto and Abundo (2024), investigates how practical and sustainable solar-powered irrigation systems (SPIS) are for rice farming in Sorsogon, Philippines. The main goals of their research were to find the best areas in the province where SPIS could be installed, to identify the most efficient system setups for rice irrigation, and to understand how these systems can help meet the Sustainable Development Goals (SDGs). They analyzed the province's land and found that about 17% of it is suitable for solar irrigation. Their study calculated that one hectare of rice land needs around 3.3 kilowatt-hours (kWh) of energy daily and would need a water pump with a peak power of 1.1 kilowatts. The most cost-effective energy setup combined solar power (producing 8,547 kWh annually) and a backup diesel generator (contributing 119 kWh annually). This combination had the lowest overall system cost of around ₱1,079,642 and the lowest cost of electricity at ₱17.79 per kWh. The research also explored how SPIS could help with broader development goals and found 27 positive impacts and 3 possible tradeoffs. In simple terms, the study showed that solar irrigation can be an affordable and environmentally friendly option for rice farming in Sorsogon, especially if local communities and farmers are involved in planning and adopting the system. The research offers useful information for those looking to implement solar irrigation systems in similar agricultural areas.

Moreover, Jenny Bartolome et al., (2023) from the University of Saint Louis in Tuguegarao City aimed to identify the best locations for installing solar-powered irrigation systems (SPIS) in Barangay San Esteban, Alcala, Cagayan. This was done in response to the ongoing challenge of irrigating agricultural lands in the Philippines, where many farms still rely on deep well pumps or rain due to the lack of formal irrigation systems. To help solve this issue, the researchers used advanced tools like Geographic Information Systems (GIS) and remote sensing, along with a method called the Analytical Hierarchy Process (AHP). These techniques helped them analyze multiple factors—such as land suitability, topography, and water availability—to determine the best places for SPIS. The results of their analysis showed that out of the 743 hectares of land in San Esteban, 286 hectares (about 38%) were not suitable for SPIS, 404 hectares (around 54%) were moderately suitable, and only 53 hectares (roughly 7%) were highly suitable for solar-powered irrigation. This kind of mapping is important because it helps decision-makers and farmers know where to prioritize investments in sustainable and renewable irrigation systems like SPIS.

III. RESEARCH DESIGN AND METHODOLOGY

This study utilized a quantitative descriptive research design to assess the economic viability and implementation challenges of the Solar-Powered Irrigation System (SPIS) among farmers in Tabuk City, Kalinga, and Quezon-Mallig, Isabela. The approach was chosen to systematically describe the current status, perceptions, and experiences of SPIS beneficiaries without manipulating variables. Data were collected through a structured survey questionnaire distributed to selected farmer-beneficiaries, focusing on demographic profiles, farming practices, income, SPIS usage patterns, perceived benefits, challenges, and suggestions for improvement. This method enabled the study to present an accurate depiction of SPIS effects on agricultural productivity, economic outcomes, and sustainability in the target communities, while also identifying gaps and issues for further improvement (Calderon & Gonzales, 2012).

The research was conducted in Kalinga and Isabela, specifically in areas covered by the Upper Chico River Irrigation System (UCRIS), chosen for their active SPIS implementation under the National Irrigation Administration (NIA). Tabuk City served as the focal point in Kalinga, while Mallig and Quezon were the focus in Isabela, both known for extensive rice and corn farming. These sites were selected due to their agricultural significance and recent SPIS integration to address water shortages and modernize irrigation. The study population included farmers, irrigation workers, and local SPIS beneficiaries, primarily members of Irrigators Associations (IAs) recognized by NIA. Purposive sampling ensured participants had at least one full cropping season of SPIS experience, with barangay officials and NIA field officers assisting in identifying qualified respondents.

Socio-demographic data showed that most respondents were older (75% aged 41 or above), predominantly male (91%), and primarily farmers (91%). Education levels varied, with 42% having primary education, 30% secondary, and 27% college degrees. Most households were medium-sized (4–6 members, 85%), and 88% of respondents owned their land, which is significant for technology adoption. Many farmers previously relied on diesel pumps (27%), with 39% spending Php 20,000–50,000 annually on fuel, indicating strong potential for economic benefits from SPIS. Additionally, 52% practiced rainfed agriculture, highlighting the need for reliable irrigation, and 55% reported areas still needing irrigation support. Most respondents (61%) had moderate annual incomes, suggesting that government-led SPIS initiatives could help demonstrate long-term economic benefits and make initial investments more manageable. These findings align with previous studies emphasizing the importance of socio-economic parameters in technology adoption (Pandey et al., 2018)1.

The main data-gathering instrument was a survey questionnaire adapted from previous SPIS research. It covered socio-demographic profiles, perceived economic viability, economic contributions, and implementation challenges, using both structured and open-ended questions. This allowed for quantitative analysis and deeper qualitative insights. The instrument's validity and reliability were ensured through focus group discussions with beneficiaries and adaptation from validated studies (Guno et al., 2022; Mitu, 2024)1.

Data collection followed a structured, ethical process, including formal permissions from authorities, coordination with community leaders, and face-to-face interviews with guidance for participants with literacy limitations. Informed consent was obtained, and confidentiality maintained. Secondary data from NIA-Kalinga supplemented the survey, with data collection lasting about four weeks. Afterward, responses were encoded and analyzed using descriptive statistics (frequencies, percentages, means), Likert scale interpretation, and thematic analysis for open-ended responses. Statistical tools such as frequency, percentage, ranking, and weighted mean were used to interpret the data and assess economic viability and challenges associated with SPIS implementation.

IV. ANALYSIS AND DISCUSSIONS

Economic Contribution of the SPIS

The adoption of solar-powered irrigation systems (SPIS) has shown a significant positive impact on various aspects of smallholder farming operations. The findings of this study indicate that SPIS adoption contributes substantially to both agricultural productivity and farmer livelihoods.

Table 1. Perceived Economic Contribution of the SPIS towards Beneficiaries

Indicators	Weighted Mean	Description
Since installing the solar-powered irrigation system, my crop yield has increased	4.09	High
The quality of my crops has improved since using the solar-powered irrigation system.	4.03	High
I have experienced a reduction in irrigation costs due to the solar-powered system.	3.7	High
The solar-powered irrigation system has reduced my overall energy and water expenses.	3.85	High
My farm income has increased as a result of using the solar-powered irrigation system.	4	High
I have been able to expand the area of land I cultivate due to the solar-powered irrigation system.	3.36	Moderate
The solar-powered irrigation system has reduced the losses of my crops.	3.88	High
SPIS has reduced my reliance on traditional fuel-based irrigation systems.	3.64	High
My financial stability has improved since adopting the solar-powered irrigation system.	3.88	High
The solar-powered irrigation system has reduced my financial risk.	3.94	High
I spend less on irrigation costs since switching to SPIS.	3.7	High
I believe the community as a whole has benefited from the implementation of SPIS?	3.03	Moderate
The adoption of SPIS has had negative social effects on our household or community	2	Low
Average Total	3.62	High

Farmers reported marked improvements in crop yield (M = 4.09) and crop quality (M = 4.03), as well as a notable reduction in crop losses (M = 3.88). These high ratings suggest that SPIS provides a reliable and efficient source of irrigation, enabling more consistent water supply and reducing dependency on erratic rainfall or unreliable fuel-powered systems. The Food and Agriculture Organization (FAO, 2018) also supports this view by highlighting how solar irrigation can address water scarcity and reduce operational costs for smallholder farmers.

From an economic perspective, the data reflect high perceived benefits related to income generation and financial stability. Farmers reported increased income (M = 4.00), reduced financial risk (M = 3.94), and improved financial stability (M = 3.88), underscoring the broader economic advantages of SPIS. These outcomes are supported by high scores in reduced irrigation costs (M = 3.70), decreased energy and water expenses (M = 3.85), and reduced reliance on fuel-based irrigation (M = 3.64). These findings are consistent with existing literature, which emphasized that SIF adoption in Pakistan has significantly contributed to reducing operational costs, increased farmers' income, reduced 17,622 tons of CO2 emissions per year, and saved 41% of water usage (Raza et al., 2022).

Despite these successes, the findings also highlight areas of moderate impact, particularly in land use and communal benefit. The ability to expand cultivated land was rated moderately (M = 3.36), which may be attributed to systemic constraints such as limited access to land, labor shortages, or the need for additional inputs beyond irrigation infrastructure. The perception of community-wide benefits also scored moderately (M = 3.03), indicating that while individual-level impacts are strong, broader communal benefits may not yet be fully realized.

Importantly, the data reflect minimal perceived negative social impacts from SPIS adoption (M = 2.00), suggesting high levels of social acceptability and limited disruption to household or community dynamics. This low incidence of negative perceptions reinforces the suitability of SPIS for integration into rural farming systems. Overall, the mean score across all indicators (M = 3.62) places the perceived impact of SPIS within the "high" category, indicating a generally positive reception and outcome among users.

In conclusion, SPIS offers a compelling solution for improving both the productivity and economic viability of smallholder farming. The system not only enhances yields and reduces operational costs but also contributes to increased financial resilience. However, to maximize its potential, policymakers and development practitioners must address barriers to land expansion and promote inclusive access, particularly among marginalized groups. Future research should explore longitudinal impacts of SPIS, the role of institutional support in technology diffusion, and its potential for scalability in diverse agro-ecological contexts.

Table 2. Challenges and Issues in the Implementation of Solar-Powered Irrigation System (SPIS)

Indicators	Weighted Mean	Description
Downtime or failures of the SPIS are frequent	2.04	Low
Regular maintenance of the system is frequently required	1.92	Low
The SPIS is highly efficient in energy conversion and water delivery	4.12	High
The SPIS is easy to operate and maintain	2.72	Moderate
I have experience major system breakdown	2.64	Moderate
I have access to technicians/service providers for SPIS maintenance	2.16	Low
The ongoing operational cost meets my expectation	3.2	Moderate
I have sufficient knowledge and trainings to operate and maintain the system	2	Low
The training provided was sufficient for me to effectively operate and maintain the System	2.16	Low
I have retained the SPIS operational and maintenance knowledge/skills from training	2.16	Low
The current installation site is suitable for the operation of SPIS	3.92	High
Usage of SPIS has negative environmental effects use (e.g water depletion)	2.08	Low
local weather conditions significantly impact the performance of SPIS	4	High
The SPIS has integrated with existing Irrigation infrastructure	4.2	High
The operation of SPIS requires additional infrastructure	3.72	High
Local stakeholders (community, LGU's, IAs) are generally supportive of the SPIS	4.08	High
Accessibility of SPIS provider for purchase and installation is viable	3.8	High
I would recommend SPIS to other farmers based on its benefits	4.16	High
I believe that the government's investment in SPIS is economically worthwhile for the farmers.	4.0	High
The solar panels and motor of the SPIS are cleaned and maintained on a regular schedule.	2.24	Low
The electrical components, including wiring and batteries, are routinely monitored for performance and safety.	2.4	Low
The operation of the SPIS adheres to current local and national regulatory frameworks.	3.6	High
the system complies with local and national regulations	3.76	High
Maintenance subsidies are being provided	2.4	Low
Average Total	3.34	Moderate

The assessment of the technical and operational aspects of the Solar-Powered Irrigation System (SPIS) reveals a generally favorable performance, with some critical areas in need of improvement, particularly in system maintenance, training, and technical support. The system was rated highly in terms of technical efficiency, with respondents indicating strong agreement that the SPIS is efficient in energy conversion and water delivery (M =

4.12) and that it has effectively integrated with existing irrigation infrastructure (M = 4.20). Additionally, the current installation sites were deemed suitable (M = 3.92), and local weather conditions were recognized as a significant influence on SPIS performance (M = 4.00). These ratings suggest that SPIS is generally well-adapted to the local agro-environmental context and that, when properly installed, it performs reliably under prevailing weather conditions. Farmers also largely affirmed that SPIS adoption does not produce harmful environmental effects, such as water depletion (M = 2.08, low), reinforcing its perceived sustainability.

Despite strong technical performance, maintenance and support-related indicators reveal operational challenges. Respondents reported low frequencies of system failures (M = 2.04) and minimal need for regular maintenance (M = 1.92), suggesting that SPIS is relatively durable. However, issues arise in terms of user preparedness and access to maintenance services. Access to technicians or service providers was rated low (M = 2.16), and respondents consistently rated their knowledge and training for operation and maintenance as insufficient (M = 2.00). Furthermore, the training provided was also seen as inadequate (M = 2.16), and retention of knowledge and skills post-training was similarly low (M = 2.16). These results highlight a gap between the system's technical potential and the capacity of end-users to manage it independently, pointing to the need for more robust, continuous, and practical training programs.

The ease of use and perceived manageability of SPIS received a moderate rating (M = 2.72), while the occurrence of major system breakdowns also fell into the moderate category (M = 2.64). These findings suggest that while the system is not overly complex, certain technical issues still arise, and the lack of adequate technical support and training may exacerbate these difficulties. Routine cleaning and maintenance practices were also rated poorly, with low means for cleaning of solar panels and motors (M = 2.24) and monitoring of electrical components such as wiring and batteries (M = 2.40). These "low" means reflect a critical challenge in the human and institutional capacity to support SPIS maintenance. Farmers reported inadequate training and technical support, which may hinder long-term sustainability of the SPIS. The findings align with literature emphasizing the role of capacity-building in the successful adoption of clean energy technologies in agriculture. Moreover, the study of Aditya and Dagmar, 2024) "Understanding Farmers' Policy Preferences for Solar Powered Irrigation Systems in Karnataka, India: A Choice Experiment Approach" finds out that the government can solve this issue by creating local service provision through training. On a broader scale, several indicators suggest positive institutional and regulatory support for SPIS. Respondents generally agreed that the system complies with local and national regulations (M = 3.76) and that its operation adheres to current regulatory frameworks (M = 3.60). There was also a strong perception of support from local stakeholders, including the community, local government units (LGUs), and irrigation associations (IAs), with a high mean score of 4.08. Accessibility of SPIS providers for purchase and installation was also considered viable (M = 3.80), suggesting a reasonably supportive market and policy environment.

Importantly, user satisfaction and advocacy for the technology were very strong. Farmers expressed a high willingness to recommend SPIS to others (M =4.16), and a significant number believed that government investment in the system is economically justified for farmers (M = 4.00). These sentiments reflect a favorable overall reception and the perceived long-term value of SPIS despite existing operational challenges.

In summary, while the SPIS is recognized for its technical efficiency, environmental sustainability, and institutional support, its sustained performance is at risk due to insufficient user training, lack of routine maintenance, and limited access to technical services. Addressing these gaps through structured training, ongoing technical support, and community-based maintenance models will be essential for maximizing the long-term benefits and reliability of solar-powered irrigation technologies.

Table 3. Duration of System Repair

Duration	Frequency	Percentage
Less Than a Week	9	27%
A Week	2	6%
More Than 2 Weeks	19	58%
Remain Unrepaired	3	9%
Total	33	100%

Based on the data, the repair process shows inefficiencies, with 58% of cases taking over two weeks and 9% remaining unresolved. These delays suggest systemic issues likely tied to workflow bottlenecks, limited resources, or supply constraints. To improve performance, it is recommended to streamline operations, enhance staff capacity, and implement tracking systems for unresolved cases.

Table 4. Additional Infrastructucture to the System

Indicators	Frequency	Percentage
Major (Batteries & Solar Panel, Canal Lining)	29	88%
Minor (Control Panel Housing & Pipe)	4	12%
None	1	3%

Based on the data, there is a clear indication that infrastructure support is critically needed, with 88% of respondents identifying major infrastructure needs, specifically batteries, solar panels, and canal lining. A smaller portion (12%) cited minor needs such as control panel housing and piping, while only 3% reported no infrastructure requirements at all.

Proposed Sustainability Plan for SPIS Implementation

To ensure the long-term functionality, efficiency, and economic benefits of the Solar-Powered Irrigation System (SPIS), a sustainability plan is essential. This plan is developed to address the pressing challenges identified in the field, such as lack of technical knowledge, limited access to repairs, infrastructural gaps, and financial constraints as presented in table 4. The proposed plan in Figure 3 provides a structured framework to enhance the system's adoption, optimize its benefits, and ensure equitable access for all farmer-beneficiaries. The following components of the plan offer practical and policy-driven solutions for strengthening the resilience and sustainability of SPIS implementation in Kalinga and Isabela. Since Sustainable Intensification of Farming (SIFs) has good effects, the government and stakeholders should prioritize the development of better ways through continual trial and iteration. Regular monitoring of solar panel efficiency and regulatory support for updating low-efficiency solar panels are needed to sustain the solar energy sector. Field demonstration projects and campaigns are essential for SIF uptake and communication of their benefits and environmental impacts (Sunny et al., 2022).

Our findings also pointed to the significance of creative management strategies emphasizing field demonstration programs and campaigns to raise environmental consciousness and benefit recipients rather than just adoption. To better understand farmers' risk management practices, we also call for more research on how people of different ages perceive SPIS and their knowledge of environmental severity and further investigation on the economic impact of Solar/Powered Irrigation system here in our country.

Table 5. Components of the Sustainability Plan for SPIS Implementation

Identified Challenges	Proposed Sustainability Plan
1. Regular monitoring and maintenance of the System score very Low (M=1.92)	Creation of Monitoring and evaluation technical performance of the SPIS
2. Lack of training and knowledge handling SPIS score Low (M=2)	Capacity Building and Technical Training Program
3. Access to Technicians and service provider	Establishment of Technical Support providers
4. provision of maintenance subsidies scores Low (M-2.4)	Policy Programs and Institutional Strengthening
5. the need of additional accessories and Infrastructure score High (M=3.72)	Additional service Infrastructure

Monitoring and evaluation of technical performance of the system. Sustainability also depends on monitoring the performance of SPIS and involving the community in its management. This component involves the regular collection of feedback from users, impact assessments, and maintenance tracking. Community engagement ensures accountability, shared ownership, and a culture of cooperation, which are essential for long-term success.

Capacity Building and Technical Training. This component focuses on equipping farmers with the necessary skills and knowledge to operate and maintain SPIS. Based on the data, it was found out that many users reported difficulty in handling the system due to a lack of training. Regular capacity-building initiatives, including community workshops, field demonstrations, and printed manuals in local dialects, should be organized. Technical training should also include troubleshooting and preventive maintenance to empower users and reduce downtime. This is supported by the study of Aditya and Dagmar, 2024) "Understanding Farmers' Policy Preferences for Solar Powered Irrigation Systems in Karnataka, India: A Choice Experiment Approach" finds out that the government can solve this issue by creating local service provision through Capacity Building Training.

Establishment of Local Technical Support Hubs. Due to the limited availability of technicians, creating localized

SPIS support hubs is crucial. These hubs would serve as resource centers where farmers can get assistance, request repairs, and purchase spare parts. They can be operated by trained local personnel or in partnership with TESDA and the National Irrigation Administration (NIA), providing a rapid-response mechanism for system breakdowns and maintenance concerns. It was found out on the data access to technical providers in the region rated low (M = 2.16). Technical knowledge and service infrastructure is needed to ensure that the systems run effectively Hartung et. Al, (2018).

Policy and Institutional Strengthening. Effective policies can institutionalize SPIS support at the local and national levels. This component advocates for stronger collaboration between LGUs, NIA, and DA in crafting SPIS guidelines, training mandates, and budget allocations. Including SPIS in barangay and municipal development plans ensures ongoing political and financial support. Financial limitations hinder farmers from maintaining the system. This component proposes the introduction of microloans, flexible payment plans, and government subsidies to make SPIS more accessible. This is supported on the study of Durga et. Al., (2024) identifying systemic barriers to the adoption and growth of solar-powered irrigation. We identify uncovered risks, lack of incentives, and lack of capacity as the key factors limiting the adoption of solar-powered irrigation.

Infrastructure Development. A significant number (88%) of respondents indicated the need for additional infrastructure such as solar panels, canal linings, batteries, and high-powered pumps. This component supports continued investment in infrastructure to improve SPIS efficiency and coverage. It emphasizes prioritizing critical upgrades and ensuring equitable distribution of infrastructure support to under-served areas.

V. SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

Summary of Findings

This study evaluated the impact, usability, and sustainability of the Solar-Powered Irrigation System (SPIS) among 33 farmers in Tabuk City, Kalinga, and Quezon-Mallig, Isabela. Most respondents were male (91%), aged 51–60 (42%), with farming as their main occupation (91%). Educational attainment was generally low, with 42% having only primary education, and most households were medium-sized (4–6 members, 85%), indicating an experienced but aging farming population that may need further training for new technologies.

Land ownership was high (88%), and the majority reported annual incomes between ₱50,000 and ₱100,000 (61%), reflecting modest economic conditions. Crop farming dominated (82%), with limited engagement in livestock or mixed farming. Many previously relied on diesel pumps, incurring high fuel costs, and over half practiced rainfed agriculture, underscoring the need for reliable irrigation.

SPIS was reported to deliver high benefits, notably improving crop yield (M = 4.09), crop quality (M = 4.03), and farm income (M = 4.00), while reducing irrigation and energy costs. The average weighted mean across all impact indicators was 3.62 (high), though expansion of cultivated land (M = 3.36) and community-level benefits (M = 3.03) were moderate, and social disruption was minimal (M = 2.00).

Technically, SPIS was rated highly for energy efficiency (M = 4.12) and integration with existing infrastructure (M = 4.20), but only moderate for ease of use (M = 2.72) and breakdown incidence (M = 2.64). Training adequacy (M = 2.16), user knowledge (M = 2.00), and technician access (M = 2.16) were low, highlighting operational support gaps and the need for better maintenance practices.

Institutional support was strong, with high confidence in regulatory compliance (M = 3.76), community backing (M = 4.08), and provider accessibility (M = 3.80). Respondents were highly willing to recommend SPIS (M = 4.16) and saw government investment as worthwhile (M = 4.00)1.

Conclusions

The Solar-Powered Irrigation System (SPIS) demonstrated substantial benefits for farmers in Tabuk City, Kalinga, and Quezon-Mallig, Isabela. SPIS significantly improved crop yield, crop quality, and farm income, while reducing irrigation and energy costs. These positive impacts were especially valuable for an aging, predominantly male farming population with modest incomes and limited formal education, who previously relied on costly diesel pumps or rainfed agriculture.

Despite these gains, the study identified notable challenges. Farmers reported moderate ease of use and system reliability, with low ratings for training, user knowledge, and access to technical support. These gaps highlight the need for enhanced capacity-building, regular maintenance, and improved technical assistance to ensure long-term sustainability and maximize system benefits.

Institutional and community support for SPIS was strong, with high confidence in regulatory compliance and widespread willingness to recommend the system. Most respondents viewed government investment in SPIS as economically worthwhile, indicating that continued public support and targeted interventions could further drive technology adoption and rural development.

Overall, while SPIS has proven effective in increasing agricultural productivity and reducing costs, addressing operational and knowledge barriers is essential for sustaining its benefits and expanding its reach among smallholder farmers1.

Recommendations

To maximize the benefits and sustainability of the Solar-Powered Irrigation System (SPIS) in Kalinga and Isabela, the following actions are recommended:

1. Regular, localized training and hands-on workshops should be provided to improve farmers' skills in operating and maintaining SPIS. Instructional materials in local dialects and ongoing technical support are crucial to address the significant knowledge gap identified among users.

2. Set up technical support centers in key areas, managed by trained personnel or in partnership with agencies like TESDA and NIA, to offer timely repairs, spare parts, and technical assistance, ensuring quick response to operational issues.

3. Introduce microloans, flexible payment schemes, and government subsidies to help farmers afford SPIS upgrades and repairs. Partnerships with rural banks and cooperatives can make these options accessible, especially for low-income farmers.

4. Continue upgrading SPIS components—solar panels, batteries, and pumps—especially in underserved areas. Regular maintenance and monitoring should be prioritized to ensure optimal system performance.

5. Integrate SPIS into local and national agricultural plans, with clear policies on funding, training, and sustainability. Formalize collaboration among LGUs, the Department of Agriculture, NIA, and other stakeholders for continuous support.

6. Ensure that SPIS benefits are equitably distributed by involving communities in decision-making and establishing feedback mechanisms, so all farmer-beneficiaries' needs are addressed.

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