

Assessing the effectiveness of Halang (Palangue) Solar Pump Irrigation System in Naic, Cavite: Promoting organizational practices and technology integration

Marjorie A. Sosong

marjorieabante1@gmail.com

Laguna State Polytechnic University, Santa Cruz Campus, Laguna, Philippines 4009

Abstract

Agriculture plays a crucial role in ensuring food security and supporting rural livelihoods, but its sustainability is often challenged by water scarcity and reliance on non-renewable energy sources for irrigation. Solar-powered pump irrigation systems (SPIS) have emerged as a promising alternative, offering an eco-friendly and cost-effective solution for farmers, especially in regions with abundant solar resources. This study aimed to assess the effectiveness of the Halang (Palangue) Solar Pump Irrigation System in Naic, Cavite, with a focus on its operational performance, sustainability, and impact on agricultural productivity. The research employed a descriptive-evaluative method, utilizing surveys, interviews, and direct field observations to gather relevant data from farmers, irrigation association members, and personnel from the NIA Cavite-Batangas Irrigation Management Office. The study focuses on key indicators including Organizational Capability, which encompasses operation and maintenance, technology adaptation, and risk mitigation, as well as Community Benefits such as cost efficiency, environmental safety, and productivity. Findings show that the system's organizational capabilities are rated as highly effective, particularly in areas of operation, maintenance, and technological integration. These aspects align well with established best practices in irrigation management, aimed at ensuring efficient water use, proper system design, and effective upkeep. Moreover, the study reveals strong and significant relationships between the system's organizational strengths and the resulting community benefits, indicating the system's overall effectiveness. However, while the link between technology adaptation and environmental safety is positive, it is only moderately strong—suggesting room for improvement in this area. These results emphasize the need for ongoing development in both organizational strategies and technological advancements to maintain and enhance the positive impact of the Halang (Palangue) Solar Pump Irrigation System within the community.

Keywords: Organizational capability; technology adaptation; risk mitigation; community benefit; cost efficiency

1. Introduction

Water is essential for survival. It plays a significant role in the development of any country. In fact, according to the Renewable and Sustainable Energy Reviews, Vol. 87, 2018, an average of five liters of fresh water is required per person per day for daily survival. Water is needed for drinking and domestic use, and it is required for large-scale irrigation, construction, and power production. While the world contains vast amounts of high-quality water, it is often not easily accessible in the areas where it is most needed. This gives rise to the need to pump water from its source to the locations where it is in demand. Water pumps have been used for centuries to fulfil this purpose.

Most commercially available water pumps operate on electricity or diesel fuel. These pumps are widely used for various purposes, with irrigation being the most common. Traditionally, electricity has been

supplied through national grids, often generated by burning fossil fuels. However, several issues arise over the years of using fuel-powered pumps. These include concerns about reliability and availability like for remote areas that lack direct access to a national grid, or when fuel supply is inconsistent or expensive, high maintenance costs, and a short lifespan. Given these challenges, along with the negative environmental impacts of burning fossil fuels, researchers have focused on finding alternatives to fossil fuels, with an emphasis on developing stand-alone water pumping systems. (Aliyu et. al., 2018)

The adoption of renewable energy sources for agricultural activities can enhance energy efficiency, support food security, and contribute to environmental sustainability in line with ecological agriculture objectives. Globally, energy-related challenges in agriculture differ based on factors such as economic development, geographical conditions, and farming methods. Developing nations often struggle with energy constraints due to inadequate infrastructure, limited access to modern technology, and a higher dependence on manual labour. Conversely, developed countries focus on optimizing energy consumption, reducing carbon emissions, and incorporating renewable energy solutions. Utilizing renewable energy in agriculture allows for targeted improvements in these areas, as the demand for both energy and food is closely linked to population growth and climate change. Implementing renewable energy and adopting efficient energy management strategies in agriculture can ease pressure on electrical grids, lower operational costs, and enhance food security. (Majeed et.al., 2023)

Among all the available renewable sources of energy that can be used for water pumping, solar photovoltaic (PV) turned out to be the most suitable one. While being clean and naturally available, solar energy has been proven to have a direct relationship between its availability and water demand. As solar intensity increases, the demand for water also rises. This correlation makes solar photovoltaic systems particularly effective for water pumping, as peak sunlight hours often coincide with the highest water demand for irrigation and domestic use. In irrigation, solar-powered pump systems have emerged as a promising alternative to traditional diesel or electric pumps. These systems utilize the abundant energy from the sun to pump water from wells, rivers, or other water sources, offering an environmentally friendly and cost-effective solution for irrigation, especially in remote or off-grid areas. (Guno & Agaton, 2022).

However, despite the numerous benefits of using solar powered pumps, its effectiveness will still depend on various factors, including local solar energy potential, water availability, pump efficiency, and the overall design of the system. This study seeks to comprehensively assess the effectiveness of solar-powered pump irrigation systems in improving water accessibility, enhancing agricultural productivity, and promoting environmental sustainability. It examines the performance of these systems in diverse geographical and socio-economic contexts, comparing their operational efficiency, cost-effectiveness, and environmental impact with conventional irrigation methods.

Through a detailed analysis of factual case studies and the evaluation of key performance indicators, the research uncovers the practical advantages and limitations of solar irrigation, identify the challenges faced by farmers and stakeholders in implementing these systems, and explore strategies for overcoming these barriers. Additionally, the study aims to highlight the opportunities for scaling solar-powered irrigation systems, offering recommendations for promoting their wider adoption as a sustainable solution to global water and energy challenges.

1.1. Background of the Study

The National Irrigation Administration (NIA) is a government-owned and controlled corporation primarily responsible for irrigation development and management. It was created under the Republic Act (RA) 3601 on 22 June 1963. Its charter was amended by Presidential Decree (PD) 552 on 11 September 1974 and PD 1702 on 17 July 1980. Both increased capitalization and broadened the authority of the Agency. The Agency's functions encompass the investigation, study, and development of the nation's water resources, primarily for irrigation purposes. NIA utilizes three schemes for the development of irrigation systems: run-

of-the-river diversion, storage or reservoirs, and pump irrigation. In pump irrigation projects, water is extracted either from underground sources or from rivers and streams. Pump systems are also commonly used in some storage or diversion schemes to lift water for irrigating higher-elevation areas or to pump groundwater to supplement the water supply from the river.

According to the National Irrigation Master plan (NIMP) 2020-2023, an assessment of the status of the irrigated agriculture sector is needed to better appreciate the baseline conditions and scenarios. This includes status of land and water resources, socio-economic conditions, agricultural productivity and farmers' income, status of irrigation development, institutional development, emerging issue and constraints in irrigation development and Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis of the irrigated agriculture sector.

Based on the National Mapping and Resource Information Authority (NAMRIA) Land Cover of 2015, Philippines has an estimated land area of around 29,359,301 ha. In terms of water resources, which is based on the Master Plan Study on Water Resources Management conducted in 1998 by the National Water Resources Board (NWRB) in cooperation with the Japan International Cooperation Agency (JICA), the landmark study estimated the country's total available freshwater resources at 145,900 M cubic meters (mcm) per year. This includes 125,790 mcm per year of surface water and 20,200 mcm per year of groundwater resource contributing about 86% and 14% of the total available water supply, respectively (NWRB-JICA, 1998).

Currently, the Philippines has approximately 10.3 million hectares of agricultural land, with around 3.1 million hectares classified as irrigable, typically with a slope of up to 3 percent, and primarily used for rice and corn farming. Though, a study conducted by the World Bank expanded the potential irrigable area, identifying more than 6.1 million hectares, including regions that are more challenging to irrigate due to steeper slopes of up to 8 percent. In these areas, Pump Irrigation Systems (PIS) are often employed to extract water. This broader definition of irrigable land has led the agency to increasingly invest in PIS to address the irrigation needs of these more difficult-to-reach areas and ensure sufficient water supply for agricultural productivity. Based on the most recent reported data, the level of irrigation development, i.e., the ratio of total actual to total potential irrigable area in the country, is estimated at 61.4%. (NIA, 2018)

However, the agency has faced several challenges in the operation and maintenance of PIS. One of the primary issues is the high cost of fuel and electricity, which directly impacts on the operational costs. In response, the agency has issued memorandum circulars outlining cost-reduction strategies and guidelines for the distribution and installation of irrigation pumps. Nevertheless, these measures have not yet been fully effective in enhancing irrigation practices or sustaining the water requirements, given the increase in the area (in hectares) to be irrigated. Thus, resulted in finding other ways for the agency to be able to deliver the quality services to the farmers and other relevant stakeholders.

In line with the modernization and innovation efforts of the Agency, NIA is harnessing the potential benefits of renewable energy sources to enhance irrigation practices. Among these, solar energy stands out as the most accessible and economically viable option. NIA continues its efforts on solar-powered irrigation projects as an innovative solution to replace costly diesel pumps, which impose a significant financial burden on Filipino farmers. These solar initiatives offer a sustainable alternative, allowing farmers to irrigate their lands without the financial strain of high fuel expenses. The solar-powered system includes solar panels, pumps, electronic controllers, storage tanks, and conveyor systems, all working together to provide an efficient and reliable water supply. Compared to traditional fuel-powered irrigation pumps, solar-powered systems are more cost-effective, particularly in terms of long-term operational expenses, reducing dependence on fluctuating fuel prices and ensuring a more stable and affordable irrigation process. (NIA, 2023)

In the CALABARZON Region, the adaptation of Solar Pump Irrigation project has started as early as 2017. And as of year 2023, the Region has installed and constructed 126 Solar Pump Irrigation Systems (SPIS) that would help alleviate the lives of more than 3,000 farmers from different parts of the region. And for this Current Year (CY) 2024, the region has a total of 51 proposed SPIS. This continued expansion

highlights the region's commitment to sustainable agriculture and improving rural livelihoods through renewable energy technologies. This continued expansion highlights the region's commitment to sustainable agriculture and improving rural livelihoods through renewable energy technologies.

However, for the province of Cavite, Solar pump projects started way back year 2018, with their pilot project, Halang (Palangue) PIP located at Barangay Halang, Naic, Cavite benefiting 30 farmers. Project construction started April of 2018 and was completed August of 2018, generating fifty-five (55) hectares of agricultural land. The said project was turned over to its Irrigators Association (IA) which is the Halang-Palangue Agrarian reform Cooperative, the end-user of the system. They will also operate and maintain the Solar Pump Irrigation System.

As the investment costs for solar-powered irrigation systems (SPIS) decrease and subsidy programs are introduced, solar technologies are becoming a viable option for both large and small-scale farmers. SPIS offer reliable and affordable energy, which can help reduce irrigation energy costs. In rural areas where diesel fuel is costly or access to the electricity grid is unreliable, SPIS provide a flexible and environmentally friendly alternative energy source. They can be applied in both large-scale irrigation systems and decentralized, small-scale irrigation setups. (FAO, 2018).

Solar-powered irrigation systems offer numerous advantages aside from the lower operational cost, including reduced greenhouse gas emissions, and improved water use efficiency. They also contribute to the resilience of farming operations by reducing dependence on unreliable grid electricity or expensive fossil fuels. However, despite the many benefits it offers, their effectiveness is still influenced by several factors, such as local solar energy potential, water availability, pump efficiency, and the overall system design. This study aims to thoroughly evaluate the effectiveness of solar-powered pump irrigation systems in improving water access, boosting agricultural productivity, and supporting environmental sustainability. It assesses the performance of these systems across various geographic and socio-economic contexts, comparing their operational efficiency, cost-effectiveness, and environmental impact with traditional irrigation methods. (Tangco, 2024)

1.2. Theoretical Framework

According to 2024, Encyclopedia of Archaeology (Second Edition), systems theory is a conceptual framework that emphasizes the interconnection between a system's components and their relationships with other systems. A system is viewed as a functional whole made up of interdependent elements. This theory takes a holistic approach, requiring the inclusion of all relevant phenomena within its framework. Typically, these elements are organized into normatively defined subsystems, each playing a specific role. The components within a system are functionally reliant on one another, meaning that any change in one part affects the rest. A system is expected to be self-contained with clearly defined boundaries. When a change occurs in any component, it disrupts the system's equilibrium, leading to an imbalance. These changes are generally attributed to external influences.

System theory offers a holistic framework for understanding complex systems and their interactions. When applied to solar pump irrigation systems (SPIS), it allows for a thorough examination of how various components (such as solar energy, water supply, pump efficiency, and agricultural practices) influence agricultural productivity. By analysing the performance of the system and its subsystems, system theory can generate insights that lead to effective policy recommendations for optimizing the use of solar-powered irrigation systems. The goal is to enhance agricultural productivity while promoting sustainability, cost-effectiveness, and resilience.

Applying systems theory to assess solar pump irrigation systems enables a comprehensive understanding of the critical factors that influence agricultural productivity. One of the most significant factors is Solar Energy Availability, as the system's efficiency is directly dependent on solar radiation. In regions with lower solar intensity, the system may struggle to generate sufficient power, reducing its ability to

operate effectively and impacting crop irrigation. Additionally, Climate variability, as changes in weather patterns, such as fluctuating solar intensity or irregular rainfall must also be considered for it can affect the performance of solar-powered irrigation systems.

Another crucial element is Water Availability, where both the quantity and quality of water play a pivotal role. Efficient irrigation systems rely not just on the total volume of water available, but also on its purity and suitability for agricultural use. Water quality issues, such as high salinity or contamination, can reduce crop productivity even if there is a large supply of water. Pumping Efficiency is equally important, as it ensures that water is delivered to crops in the right amounts and at the appropriate times. A highly efficient pumping system minimizes energy consumption and ensures that irrigation schedules align with crop needs, particularly in regions with irregular water availability. The overall System Efficiency also impacts the system's success. This encompasses the performance of the solar panels, pumps, and storage infrastructure. The effectiveness of these components directly influences the ability of the system to irrigate large areas with minimal energy consumption. A well-designed system, with optimized components, can significantly boost agricultural yields by ensuring that water is distributed evenly and efficiently.

Given the insights derived from applying system theory, several policy recommendations can be made to enhance the effectiveness of solar pump irrigation systems and improve agricultural productivity. By applying system theory, policymakers can gain a comprehensive understanding of how solar pump irrigation systems work and the factors that influence their success in boosting agricultural productivity. The insights generated from this systems approach can guide the development of policies that address technological, financial, environmental, and socio-economic challenges, ultimately enhancing the effectiveness of solar-powered irrigation systems and promoting sustainable agricultural practices.

Aside from the systems theory, there are other related theories that may support in assessing the effectiveness of the SPIS. One is the Technology Adaptation Theory. Technology adoption refers to the acceptance, integration, and embracement of new technology to make full use of it. It is a complex process where individual perceptions of technology are formed within a socio-cultural context, it examines the individual and the choices an individual makes to accept or reject a particular innovation. The key to adoption is that the adopter must perceive the idea, behavior, or product as new or innovative, thus technology adoption can refer to either organizational adoption or adoption at individual level. (Granic, A. 2023)

Technological Adaptation is key to improving system performance and ensuring long-term sustainability. The integration of advanced technologies, such as automated irrigation controls, soil moisture sensors, and water-saving technologies, can further enhance efficiency. These innovations enable the system to respond dynamically to changing environmental conditions, optimize water usage, and allow for better management of resources. As agricultural needs evolve, these technologies help make solar pump irrigation systems more flexible, resilient, and capable of meeting the growing demands of modern farming practices. This study aims to analyze how farmers adopt solar-powered pumps compared to traditional irrigation methods. Consider factors like perceived ease of use, relative advantage, compatibility, trialability, and observability.

Community participation is also a key to successful operation and maintenance of the system. Hence, the Community of practice theory will take place. Community of practice theory is a theory that explores how community engagement can support and enhance the learning and development of individuals and groups who share a common domain of interest, practice, or profession. Community of practice theory defines a community of practice as a group of people who engage in a process of collective learning and knowledge creation through regular interaction, collaboration, and reflection. Community of practice theory suggests that community engagement can foster and sustain communities of practice by providing opportunities and resources for people to connect, communicate, and cooperate with each other, and to share their expertise, experiences, and challenges, as well as to innovate, experiment, and improve their practice.

And lastly, the Productivity Theory. "Productivity is commonly defined as a ratio of a volume measure of output to a volume measure of input use". At its most fundamental level, productivity measures

the amount produced by a target group (country, industry, sector, farm or almost any target group) given a set of resources and inputs. The concept of productivity is simple: at a given level of input, there is a given level of output. More productive societies and processes will yield more output at the same level of input. In this study, theory focuses on how inputs (e.g., water, labor) are converted into outputs (e.g., crops). It includes the Cobb-Douglas production function, which can model productivity changes. Assess how the introduction of solar-powered pumps affects the productivity of agricultural land. Compare crop yields and input-output ratios before and after implementation

1.3. Conceptual Framework

The aim of this study is to assess the effectiveness of solar-powered pumps in irrigation infrastructure development and their impact on agricultural productivity. The conceptual framework outlines the key concepts, relationships, and variables involved. It serves as a guide for understanding how solar-powered irrigation influences farm efficiency, and the socio-economic well-being of farmers.

This study used the Input-Process-Output framework as shown below. In quantitative research, the Input-Process-Output (IPO) conceptual framework visually represents a system's elements by showing how inputs are transformed through a process to produce outputs, aiding in understanding research relationships.

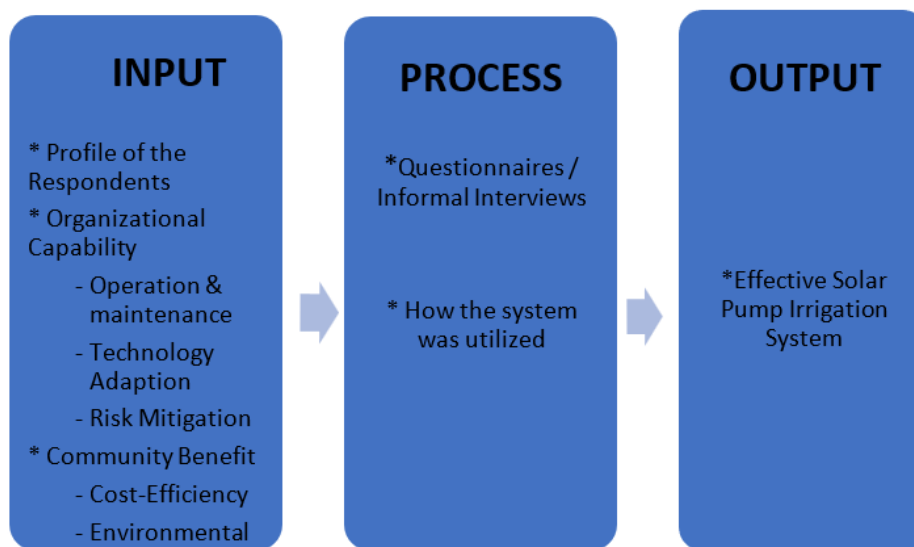


Figure 1. The Research Paradigm of the Study

1.4. Statement of the Problem

The purpose of this study is to assess the effectiveness of Solar Pumps Irrigation Systems of the National Irrigation Administration (NIA) in CALABARZON Region specifically the Halang (Palangue) Solar Pump Irrigation System in Naic Cavite.

It sought to answer the following questions:

1. What is the Profile of the respondents in terms of:
 - a. Age;
 - b. Sex; and
 - c. Educational Attainment?

2. What is the level of Organizational Capability of the Irrigators Association (IA) in terms of:
 - 2.1 Operation and maintenance;
 - 2.2 Technology Adaptation; and
 - 2.3 Risk Mitigation?
3. What is the level of community benefit for the Irrigators Association derived from the program, Solar pump Irrigation System of NIA, in terms of:
 - 3.1 Cost Efficiency;
 - 3.2 Environmental Security; and
 - 3.3 Productivity?
4. Is there a significant relationship between the Organizational Capability and Community Benefit of the Irrigators Association on the Halang (Palangue) Solar Pump Irrigation System of NIA?

1.5. Research Hypothesis

There is no significant relationship between the Organizational Capability and Community Benefit of the Irrigators Association on the Halang (Palangue) Solar Pump Irrigation System of NIA.

1.6. Scope and Limitation of the Study

This study focused on assessing the effectiveness of solar-powered pumps and provide a comprehensive, well-documented analysis of their economic and environmental impacts. For this study, one irrigation system in the province of Cavite was chosen, specifically the Halang (Palangue) Solar Pump Irrigation System. The primary data collection method involved structured questionnaire-checklist, which will be supplemented by unstructured interviews and direct observations. These methods ensure a thorough evaluation of both the operational performance and the broader implications of the transition to solar-powered irrigation on agricultural productivity, energy savings, and environmental sustainability.

Significance of the Study

The researcher believes that the study will help assess the effectiveness of using Solar powered pump for irrigation purposes to increase agricultural productivity. The findings of this study could have significant contributions to the following sectors:

National Irrigation Administration. The study provides the agency with a detailed analysis assessing the efficiency, cost-effectiveness and environmental benefits of using solar powered pumps for irrigation. As well as a policy recommendation that the agency may use as reference in their future project proposals. This helps guide future projects and encourages broader use of sustainable irrigation.

Design Engineers. Since one factor in the effectiveness of Solar Pump Irrigation System is the overall system design, this research may help designers to have a broader understanding on other factors that should be considered in the design data, like for instance is the geographic location, the amount of rainfall, and the intensity of solar energy.

Other agency in the field of Agriculture. They could use this research as a basis for the possible adaption of solar pump irrigation systems by promoting good practices of the chosen project, other agencies may adapt or improve their existing irrigations systems and its operation and maintenance programs.

Farmers / Irrigator's Association. Farmers are the ultimate beneficiaries of the NIAs Solar Pump Irrigation Projects, and with this study, it can help farmers to have a better understanding of how the system works, and the advantages and disadvantages of using it. In this regard, this study will help them in the decision making on whether or not to shift from conventional pump systems to Solar pump irrigation systems.

Community. One cited advantage of Solar Powered Pumps is that it is environmentally friendly compared to the fuel fed pumps. If this study can demonstrate that the high initial cost of solar-powered irrigation systems (SPIS) can be offset by factors such as savings in operation and maintenance costs,

environmental benefits, and economic viability, it could encourage the government and other investors to adopt solar-powered pumps. This shift would not only promote a healthier environment for the community but could also potentially reduce gasoline costs due to lower demand.

Future researchers. This research may serve as a reference to their research work as they undertake the similar study in the future and help in the promotion and improvement of the usage of solar pump irrigation system.

Definition of Terms

The following terms are defined for clearer understanding of this study:

Agriculture. It is the practice of cultivating land, raising animals, and producing crops for food and other products.

Agricultural Productivity. It is measured as the ratio of agricultural outputs to inputs

Array. It Refers to the collection of photovoltaic (PV) modules electrically wired together on one structure to produce a specific amount of power.

Cost efficiency. It is the process of reducing costs while maximizing value in an organization. It's a measure of how much resources are used to produce a given quantity of goods.

Direct Current (DC). It is the Electric Current (flow of electrons) in which the flow is in only one direction.

Economic Analysis. It is a systematic way to evaluate the costs and benefits of economic decisions.

Energy. It is the capacity of doing work as measured by the capability of doing work (potential energy), or the conversion of this capability to motion (kinetic energy).

Energy Consumption. It is the use of energy as a source of heat or power as an input in the manufacturing process.

Environmental Impact. It is the effect of human activity on the natural environment, such as land, water, plants, animals, and the atmosphere.

Groundwater irrigation. It is the use of groundwater to water crops and other agricultural needs.

Inverter. This converts the electricity from the original Direct Current (DC) to usable Alternating Current (AC).

Irrigation. It is defined as human intervention to modify the spatial & temporal distribution of water occurring in natural channels, depressions, drainage ways, or aquifers and to manipulate all or part of this water to improve production of agricultural crops or to enhance growth of other desirable plants.

Irrigation System. It is set of physical and social elements employed to acquire water from a naturally concentrated source.

Operation and Maintenance. This refers to operation and maintenance (O&M) of an irrigation system involves the day-to-day activities required to ensure the system is running properly.

Operation – It is the running pumps, gates, turnouts, and drainage ditches, and operating storage and diversion dams.

Maintenance – It is the checking for wet and dry areas, monitoring the pump system, and ensuring the central controller is programmed correctly.

Photovoltaic Generation. It refers to the process of converting solar energy into electricity to power a water pump

Pipes. It is an irrigation pipe is a tube that directly moves water from the source, like a reservoir or well, to your crops.

Productivity. This refers to the ability to do as much work as possible in a particular period. It is also a measure of performance that compares the output of a product with the input, or resources, required to produce it.

Pump Controllers. These are the controllers that regulate the water pump and allow it to be turned on and off. They can increase the life of the water pump by protecting it from electrical irregularities or motor damage if it keeps running when a water source runs dry. Controllers also maximize water delivery.

Renewable Energy. It is the energy derived from natural sources that are replenished at a higher rate than they are consumed.

Risk Mitigation. It is the process of reducing the impact of potential risks by developing a plan to manage, eliminate, or limit setbacks. The goal is to protect assets, maintain operational continuity, and enhance resilience in facing unforeseen challenges.

Solar Panels. These are also called the solar photovoltaic (PV) system, solar panels take the sun's photons and convert them into electricity in three basic steps. First, Solar cells within solar panels absorb photons from the sun and convert them into direct current (DC) electricity, then an inverter converts DC electricity to Alternating Current (AC) electricity, and lastly, this AC electricity is used to operate the water pump.

Solar water pumps. These are innovative device that utilizes solar energy to power water pumps. These pumps operate by using sunlight to generate electricity for the motor which helps in drawing water.

Sustainable Agriculture. It is a farming system that aims to produce high-quality food while protecting the environment and the people who grow it.

Technology adoption. It is the process by which people or organizations accept and use new technologies. It involves learning and adapting to new technologies.

Water Pump Motor. It is the equipment that takes water from any available water source, including from underground or another water source, that can be used for irrigation, household, or other purposes.

Water Tank. It is the structure where pumped water is stored in an elevated water tank and gravity is used for irrigation. The height of the water in the tank determines the pressure of the irrigation system.

1.7. Review of Related Studies and Literature

A vast array of reports, case studies, product details, websites, and academic papers is available on solar-powered irrigation. A systematic review of this information was conducted, and the most relevant sources have been included in the references. However, several older reports have become outdated due to the rapid evolution of the solar-powered irrigation sector in recent years. Advances in efficiency and significant reductions in investment costs have transformed the landscape, enabling configurations and system designs that were previously unfeasible. Additionally, numerous innovations and technical advancements have further enhanced the capabilities and appeal of these systems.

1.7.1. Related Literature

Irrigation is a vital agricultural practice that supports crop diversification and boosts yields on farms worldwide. However, traditional irrigation systems often rely on conventional energy sources such as electric motors or fuel-powered generators, which can be costly and environmentally taxing. To address these challenges, photovoltaic (PV) energy is increasingly being integrated into agricultural systems, particularly in regions where access to an electrical grid is limited or nonexistent. Solar energy, the most abundant and accessible energy source on Earth, offers a promising solution to the ongoing energy crisis while promoting sustainability.

Having established the fact that solar energy is renewable and limitless and while it may seem like maintaining the solar panels used to harness it would be challenging, this is not entirely accurate. Solar panels require minimal upkeep, needing only an occasional wipe-down every few months to ensure optimal performance. Once installed, solar panels are highly user-friendly and require little effort to operate. They are essentially "plug-and-play" devices, designed to function reliably without constant attention or intervention. (SOLENERGY 2024)

Even in the rare event of a malfunction, maintenance is straightforward. Solar panel providers, such as SOLENERGY, offer comprehensive "operations and maintenance" services to their clients. Their skilled

local service teams are equipped to troubleshoot and resolve any issues related to their products. These teams possess extensive expertise in solar energy systems and work closely with clients to enhance their technical knowledge, ensuring the panels deliver high performance and long-lasting reliability.

In the Philippines, the agricultural sector is predominantly composed of small-scale farmers, with 57% cultivating land areas of 1 hectare or less, and 32% managing farms between 1 to 3 hectares, out of a total of 7.2 million hectares (World Bank, 2021). However, these farmers often face limited opportunities for improving their livelihoods due to small landholdings, inadequate knowledge of production and marketing, and restricted access to financing.

Their productivity is further constrained by several challenges, including limited access to irrigation water, rising diesel costs for irrigation, and the adverse effects of changing climate patterns. In response to these issues, the integration of renewable energy technologies into agricultural practices has recently emerged as a promising and sustainable approach to enhance productivity, reduce costs, and support the long-term viability of small-scale farming. Among these technologies, solar-powered irrigation systems have gained particular attention for their reliability, cost-efficiency, and alignment with farmers' water needs.

According to the Philippine Agricultural and Biosystems Engineering Journal, the performance of Solar-Powered Irrigation Systems (SPIS) is influenced by several factors, including the output of the photovoltaic (PV) array, the efficiency of the controller, the total head (the height of the pump from the water source to the delivery outlet), the size of the inlet and outlet pipes, the number of bends in the pipes, water quality, and the efficiency of the pump set. The system's performance is also significantly affected by the amount of available solar irradiance. However, the performance of the SPIS can be enhanced, even under overcast conditions, by increasing the design capacity of the PV array. (Merciales et.al., 2022).

The Photovoltaic technology, which converts sunlight into electricity through solar panels composed of photovoltaic cells, has become an efficient means of harnessing solar energy. This technology is already widely utilized for powering streetlights, water heaters, and residential energy systems. As the cost of solar panels continues to decline, their applications are expanding into more sectors, including agriculture. One notable application is the use of solar-powered irrigation systems (SPIS), which are proving to be a game-changer for farmers, especially in countries like the Philippines. SPIS provides an eco-friendly and cost-effective alternative to conventional irrigation methods. These systems use solar panels to generate electricity, powering water pumps that deliver water to crops. After the initial investment in equipment and installation, SPIS offers free energy for years, reducing operational costs and dependence on fossil fuels. The benefits of SPIS go beyond cost savings. They provide farmers with energy independence, ensuring a reliable water supply even in remote areas with no access to the electrical grid. Additionally, these systems support environmental conservation by significantly reducing greenhouse gas emissions associated with traditional energy sources. For farmers in the Philippines, where agriculture is a cornerstone of the economy and livelihoods, SPIS represents an opportunity to enhance productivity, reduce costs, and contribute to a more sustainable future. (IRENA, 2015).

As the investment costs for solar-powered irrigation systems (SPIS) continue to decrease, and with the introduction of subsidy programs for SPIS, solar technologies are becoming a feasible option for both large and small-scale farmers. SPIS offers reliable and cost-effective energy, potentially lowering irrigation energy expenses. In rural areas where diesel fuel is costly or where access to a stable electricity grid is limited, solar systems present a flexible and environmentally friendly alternative. These systems are suitable for both large-scale irrigation projects and decentralized, small-scale applications (FAO, 2022).

The article titled *Solar Empowerment in Agriculture: Investigating Photovoltaic Energy's Impact on Efficiency Among Wheat Farmers* explores how integrating solar-powered irrigation systems can significantly improve the efficiency of wheat farming operations. The study evaluates the impact of photovoltaic (PV) energy on key performance indicators such as water use efficiency, cost-effectiveness, and overall crop productivity. By comparing PV-powered systems to conventional energy sources, the research demonstrates that solar irrigation not only reduces operational costs but also optimizes water consumption,

leading to higher yields. These findings highlight the critical role of renewable energy technologies in advancing sustainable agricultural practices, ultimately supporting greater food security and environmental conservation. (Xie et.al., 2021)

According to Roblin (2016) in the article, "Solar-powered irrigation: A solution to water management in agriculture?", that there are rural areas, particularly in developing and emerging countries, lack reliable access to the electricity grid. As a result, farmers cannot depend on traditional irrigation systems. In such cases, using an independent and alternative energy source, like solar power, offers a reliable solution for farmers and helps prevent overloading of the public grid. While diesel pumps are slightly more efficient than AC-powered pumps and offer greater flexibility, they rely on fuel availability, which can lead to environmental impact. Diesel-powered pumps are also cheaper initially, but their operating costs are high and fluctuate with diesel prices. In contrast, solar-powered systems, though more expensive upfront, use free energy, meaning that after the amortization period, there are no operating costs, aside from maintenance. Consequently, solar pumps prove to be a cost-effective, long-term investment.

While diesel-powered pumps are generally more efficient than AC-powered pumps and provide greater operational flexibility, they come with significant drawbacks. These systems are reliant on the availability of diesel fuel, which can fluctuate in price and lead to high and unpredictable operating costs. Furthermore, diesel pumps contribute to environmental degradation due to their reliance on fossil fuels. On the other hand, although solar-powered systems are more expensive to install initially, they harness free energy from the sun. After the system has paid off its installation cost, the operational expenses are minimal, with only maintenance costs remaining. This long-term reduction in operating costs makes solar pumps an economically viable investment, especially considering the environmental benefits of using renewable energy. In summary, solar-powered irrigation systems offer a sustainable, cost-effective solution for farmers, positioning them as a long-term investment with lower operational costs and reduced environmental impact.

The article titled Solar Water Pump, examines the use and benefits of solar-powered water pumping systems, particularly in agricultural and rural areas. It explains how photovoltaic (PV) technology converts sunlight into electrical energy to power water pumps, offering a renewable and sustainable alternative to traditional energy sources. The paper highlights the advantages of PV water pumps, including their simplicity, minimal maintenance requirements, and suitability for remote locations where access to grid electricity is limited or unreliable. However, it also discusses key challenges hindering widespread adoption, such as the relatively high upfront costs and the need for ongoing technological improvements to increase efficiency and lower expenses. Despite these barriers, the study emphasizes the growing global interest in solar water pumps, driven by their potential to provide affordable, eco-friendly water supply solutions that support agricultural productivity and rural development. Overall, the article advocates for continued innovation and investment to make solar water pumping systems more accessible and cost-effective for a wider range of users. (Alkhubaizi, et.al. 2017)

In relation to that, the article Solar Powered Water Pumping Systems by B. Eker (2005) discusses the design, operation, and benefits of using solar energy to power water pumps, particularly in agricultural and remote areas. It explains how photovoltaic (PV) panels convert sunlight into electricity to drive pumps, providing a clean and renewable alternative to conventional diesel or electric pumps. The study highlights the advantages of solar-powered pumping, including low operating costs, minimal maintenance, and independence from unreliable grid electricity. It also addresses technical considerations such as system sizing, pump selection, and the importance of matching the PV array capacity to water demand. Overall, the article emphasizes that solar water pumping systems offer a sustainable and cost-effective solution for irrigation and water supply, especially in regions with abundant sunlight and limited access to traditional energy sources.

1.7.2. Related Studies

Irrigation is a common and vital practice on farms worldwide. Traditional irrigation systems often

rely on electric motors and fuel-powered generators, which consume large amounts of conventional energy. However, as the cost of solar panels continues to decrease, photovoltaic (PV) technology is gaining traction across various sectors, including agriculture, where irrigation is a key economic activity. In the study “Technical and Economic Analysis of Solar Photovoltaic Water Pumps against Conventional Systems in Common Crops in Ilocos Sur, Philippines”, it compared PV-powered irrigation systems with conventional irrigation methods for typical crops grown in Ilocos Sur. Equipment sizes were optimized based on irrigation requirements, rainfall data, farm size, and available equipment options in the region, with economic evaluations conducted on a one-hectare basis. A 20-year cash flow analysis was used to determine the levelized cost of water pumping. Results showed that to make full use of farmland throughout the year, alternating rice and corn planting is necessary. While solar pump systems require a higher upfront investment than conventional systems, their low fuel and maintenance costs make them more economically viable over time. Over the 20-year lifespan, the cost to pump one cubic meter of water using a solar pump was PHP 1.35, significantly lower than the PHP 5.44 cost of using a gasoline-powered pump—about four times more expensive based on prices at the time of the study. (Orpia et.al. 2021)

Solar irrigation systems play a key role in sustainable agriculture, addressing global issues including greenhouse gas emissions, pollution, and sustainable production. An increasing number of studies are discussing the role of renewable energy technologies in agriculture from technical, economic, and environmental points of view. Using the case of the Philippines the study of Guno and Agaton (2022), titled Socio-Economic and Environmental Analyses of Solar Pump Irrigation System for sustainable Agricultural Production, the research applied various methodologies including economic analysis, environmental impact assessment, and social acceptance comparing the advantages of using solar over diesel-powered pump systems for irrigation. The findings indicate that while solar-powered irrigation systems require a higher initial investment compared to diesel-powered systems, they have significantly lower maintenance and operational costs. Over the system's lifecycle, this translates to substantial savings for farmers on fuel expenses. Considering the volume of diesel typically consumed per hectare, the transition to solar PV systems can prevent a considerable amount of greenhouse gases and air pollutants from being released into the atmosphere.

Using data on agricultural diesel consumption and the country's annual fuel demand, the shift to solar technology for irrigating rice farms presents a major opportunity for energy savings in the agricultural sector. Economic analysis shows that solar irrigation systems are a sound investment, with an average positive net present value (NPV) of USD 4,517 per hectare, a strong return on investment (ROI) of 315%, and a relatively short payback period of 2.88 years. However, the costs and benefits vary widely depending on the specific circumstances. The analyzed indicators range from an NPV of USD 1,255 to USD 68,582 per hectare, ROI from 30% to 2,958%, and payback periods from 0.34 to 30 years. This variability reflects differing levels of acceptance among farmers. Approximately 69% of marginal farmers expressed interest in adopting solar irrigation systems, while 26% were uninterested, primarily those with smaller landholdings and minimal fuel usage for irrigation.

Although awareness of the financial benefits of solar irrigation systems is relatively high, there is a notable lack of understanding regarding their contribution to environmental sustainability. This highlights the need for greater emphasis on educating farmers about the ecological advantages of adopting solar-powered technologies.

Therefore, solar irrigation systems have no variable operational costs since they do not rely on fuel and operate using energy from sunlight. However, there are fixed maintenance costs, which cover labor, transportation, and the replacement of the submersible water pump. This pump typically needs replacement every 8 to 15 years, depending on factors such as siltation and water source quality. The solar panels themselves require minimal maintenance, mainly consisting of regular cleaning to ensure optimal sunlight capture. (Guno & Agaton, 2022).

The study titled Solar Empowerment in Agriculture: Investigating Photovoltaic Energy's Impact on

Efficiency Among Wheat Farmers examines the role of solar-powered irrigation systems in enhancing agricultural productivity. The research focuses on wheat farmers and assesses how the integration of photovoltaic (PV) energy influences operational efficiency. By analyzing various performance metrics and comparing them with traditional energy sources, the study highlights the potential benefits of adopting solar energy in farming practices. The findings suggest that PV-powered irrigation systems can lead to improvements in water usage efficiency, cost savings, and overall farm productivity. These insights underscore the importance of sustainable energy solutions in modern agriculture and their contribution to enhancing food security and environmental sustainability. (Khan et.al., 2024).

Irrigation water plays a crucial role in agricultural production. In many parts of the world, market-driven agricultural practices would be impossible without irrigation. The reliance of farm households on irrigation depends on factors such as their geographical and agro-climatic location, local hydrological and soil conditions, and the specific water needs of their crops. Solar-powered irrigation systems offer a reliable and cost-effective energy source, potentially lowering energy expenses for irrigation. In rural areas where diesel fuel is costly or access to a reliable electricity grid is limited, solar systems provide a flexible and environmentally friendly alternative. These systems are suitable for both large-scale and small-scale, decentralized irrigation applications. (Merciales et.al., 2022).

In the study, Promoting Sustainable Agriculture Using Solar Irrigation: Case Study of Small-Scale Farmers in the Philippines by Agaton and Guno (2024) explores the potential of solar-powered irrigation systems (SPIS) as a sustainable agricultural solution for small-scale farmers. It highlights the economic viability of SPIS, noting that while the initial investment ranges from USD 1,800 to 2,400—significant for farmers earning an average of USD 2,000 annually—the long-term savings on fuel and maintenance make it a cost-effective option. Environmentally, SPIS significantly reduces greenhouse gas emissions and air pollutants, supporting climate action goals. Social acceptance is promising, with 69% of surveyed farmers expressing interest in adopting the technology. However, barriers such as high upfront costs, limited technical knowledge, and concerns about reliability still hinder widespread use. The study recommends strong policy support, including financial incentives and training programs, as well as community engagement to tailor systems to local needs. Overall, SPIS is presented as a viable tool to enhance agricultural sustainability, improve livelihoods, and contribute to climate resilience in the Philippine farming sector.

It was supported by the study titled Reliability and Performance Evaluation of a Solar PV-Powered Underground Water Pumping System by Ahmed et al. (2023) examined the performance of a 10-horsepower solar-powered water pump system in Bani Salamah, Egypt, over a six-month period from December 2020 to June 2021. It focused on how environmental and technical factors—such as solar irradiance, panel temperature, and system efficiency—affect the pump's operation. Results showed that water output increased with higher solar irradiance, with daily volumes ranging from 129 cubic meters in December to 181.8 cubic meters in June. However, rising panel temperatures, which reached up to 44°C, negatively impacted performance. The study found that every 1°C increase in panel temperature resulted in a 0.48% drop in system efficiency. The highest panel efficiency, 13.8%, was recorded in March, while the lowest was 13% in December. These findings emphasize the need to account for environmental conditions in the design and management of solar irrigation systems and suggest that improvements such as better panel positioning and cooling methods could enhance overall system reliability and efficiency.

Another study to support that which was authored by Seguban, R.G. et.al. (2016), A Portable Solar-Powered Generating Apparatus for Irrigation System of Small-Scale Farming “Tubig at Ilaw Mula sa Araw”, by, it was concluded that designing a solar-powered portable generator for irrigation systems using a submersible pump is both technically feasible and highly practical for reducing farming inputs. This versatile device can also support various applications such as lighting, ventilation, and charging. The project aims to promote environmental sustainability while boosting income opportunities by establishing a solar-powered water system tailored for both urban and rural irrigation needs.

The study recommended bigger size solar panels for more efficient charging, for the purpose of

nighttime irrigation where PV powered pumps cannot operate due to lack of solar irradiation, fully-charge spare batteries should be used.

Same as inclusion of water reservoir or water tank as storage of excess pumped water, a water reservoir is essential for nighttime irrigation when using PV pump systems. The reservoir's capacity should meet the minimum daily water requirements to serve as a security stock. This approach is most practical for very small plots, such as field beds.

With regards to cost efficiency, a study of Cost benefit Analysis Between Solar-Powered and Diesel Fuel-Fed Pumps of NIA-UPRIIS by Bencalo et.al. (2021), it was highlighted that the adoption of solar-powered pumps has proven to be both more efficient and cost-effective compared to diesel-powered pumps. It is estimated that the use of solar-powered pumps could save approximately Php 277,028,649.18 over time. Beyond the financial benefits, these pumps offer significant environmental advantages. They operate quietly, reducing noise pollution, and eliminate the harmful emissions associated with diesel-powered generators, contributing to cleaner air and a healthier environment.

Given these substantial benefits, researchers strongly recommend that the agency expand the installation of solar-powered pumps across all its irrigation projects. This initiative would not only provide immediate environmental gains but also lead to significant long-term cost savings for the Philippine government. The widespread implementation of solar-powered irrigation systems could enhance agricultural productivity, reduce reliance on fossil fuels, and position the country as a leader in sustainable agricultural practices.

2. Methodology

This chapter outlines the research design, study locale, sample and sampling procedures, participants, research instruments, data collection methods, and data analysis techniques. It will detail the processes used to determine the responses of the sample population, as well as the procedures for collecting and analyzing the data obtained.

2.1. Research Design

The research aimed to provide a systematic and accurate description of a population and its situation. Descriptive research was suitable for the study as it sought to identify various characteristics, frequencies, trends, and categories. Descriptive research is devoted to the gathering of information about prevailing conditions or situations for the purpose of description and interpretation.

This study used the Descriptive-Quantitative Research methodology to gather necessary data from respondents using survey questionnaires supplemented by unstructured interviews and observations. A complete enumeration of the respondents was conducted using a pre-tested interview schedule. Focus group discussions and participant observation were also employed. The data were presented in frequency distribution tables.

The overall conditions of each variable were calculated using the average weighted score. Interactions with participants were conducted through surveys and interviews to gather the necessary information.

2.2. Respondents of the Study

The respondents of the study are composed of thirty (30) farmers benefited by the Halang (Palangue) Solar Pump Irrigation Project of NIA in the province of Cavite.

2.3. Sampling Technique

Sampling refers to the process of selecting a portion of the population that meets specific criteria to be studied. A sample is a subset of the population chosen to take part in the research. In this study, a purposive sampling method was employed, which is commonly used in phenomenological research.

Purposive sampling involves selecting participants who have knowledge of the issue at hand due to their direct involvement and experience with the situation.. In this study, the farmers or the end-users of the solar irrigation systems were found to be the best source of rich and valuable information regarding their experience and observations, as they are experts of their own farming practices.

The respondents were the thirty (30) farmer beneficiaries of the completed Halang (Palangue) Solar Pump Irrigation System constructed by the National Irrigation Administration (NIA) – in the province of Cavite. They were chosen to evaluate the system's impact on their farming.

2.4. Research Procedure

After the research proposal was approved, the researcher collected relevant information to address the research problem. Preliminary readings of articles, journals, and previous studies helped in conceptualizing the study and designing the questionnaires. The study commenced once the researcher obtained permission through a letter addressed to the Division Manager of NIA Cavite-Batangas Irrigation Management Office (CBIMO). The approved request was included with the survey questionnaire used for the interviews. To support the information obtained using a questionnaire, documentary analysis and interview of the respondents was also done.

The interview, conducted by the researcher using the prepared survey questionnaire, took place during scheduled coordination meetings with the Irrigators Association or during periodic field inspections and validations. The respondents were given sufficient time to answer the questions to ensure a better understanding and thorough responses. Once the required number of respondents was reached, the completed research tools were collected. The responses were then tallied and organized in frequency distribution tables. The data was analyzed using various statistical methods, and the results were used to draw conclusions and formulate recommendations.

2.5. Research Instruments

The primary instrument used to gather data was a set of questionnaire-checklists, supplemented by unstructured interviews and observations. This was the most suitable method, as it provided all the necessary information the researcher sought, with respondents answering based on the given options. This approach ensured both quantitative and qualitative data were effectively collected for comprehensive analysis.

The researcher's survey questionnaire was submitted for approval and validation by the panel members and experts in public administration. It was composed of three (3) parts. Variables of the study and corresponding measurement include profile of the respondent, location and extent of the system, organizational capability of the IA, and the level of community benefit of the Solar pump irrigation system. This format allowed a thorough evaluation of the system's impact and key factors. It covered respondent profiles, system details, organizational capacity, and community benefits.

Survey questionnaires were distributed to collect data from the selected farmers benefited by the Halang (Palangue) SPIS in the province of Cavite. The questionnaire used a 5-point Likert scale to gauge agreement or frequency to capture qualitative insights. Respondents will be asked to rate their perceptions, practices, and experiences on a structured scale, providing quantitative data for analysis.

Table 1. The Five-Point Likert Scale to Measure the Respondents Response

SCALE	NUMERICAL VALUE	DESCRIPTIVE VALUE
5	4.50 - 5.00	Extremely Effective
4	3.59 - 4.49	Very Effective
3	2.50 - 3.49	Moderately Effective
2	1.50 - 2.49	Slightly Effective
1	1.00 - 1.49	Not at all Effective

2.6. Statistical Treatment of Data

The collected data was tabulated and analysed using descriptive, narrative, and statistical methods. The researcher also calculated the mean, which represents the average value used to determine the central tendency of the data. It is found by summing all the data points in the population and dividing the total by the number of points. The resulting value is referred to as the mean or average. These methods helped provide a clear and accurate interpretation of the survey results.

To determine the relationship between the identified variables on the effectiveness of the Solar Pump Irrigation System, the Pearson Correlation method was used which answers the hypothesis. A Pearson Correlation is a number between -1 and 1 that indicates the extent to which two variables are linearly related.

Pearson Correlation Coefficient

Guilford developed the Pearson Correlation Coefficient "R" test in 1956 in an effort to quantify and analyze the linear relationship between two variables. It is used to determine whether a linear relationship between two variables exists and how strong it is (as indicated by the p-value and coefficient r, respectively). Only when the underlying assumptions are true is this test used.

The Rule of Thumb presented by Guildford (1973) was adopted for interpreting the relationship strength. Table 2 summarizes Guildford's (1973) Rule of Thumb for interpretation of correlation coefficient (r)

Table 2. Guildford's (1973) Rule of Thumb for Interpretation of Correlation Coefficient

<i>r</i>	Interpretation
< .20	Slight, almost negligible relationship
.20 - .40	Low correlation, definite but small relationship
.40 - .70	Moderate correlation, substantial relationship
.70 - .90	High correlation, marked relationship
> .90	Very high correlation, very dependable relationship

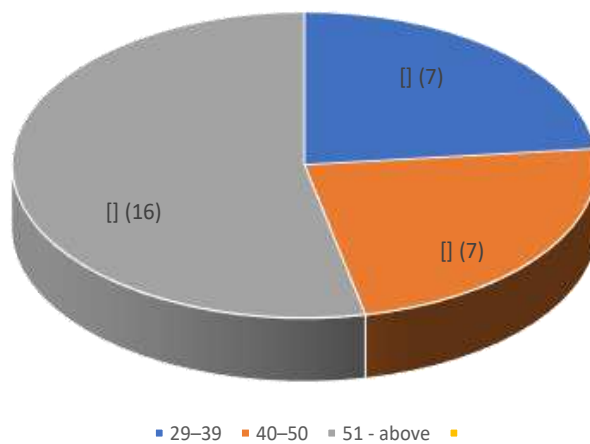
3. Results and Discussion

This chapter presents the data gathered, the results of the statistical analysis done and interpretation of findings. These were presented in tables following the sequence of the specific research problems stated in the previous chapter.

3.1. Profile of the Respondents

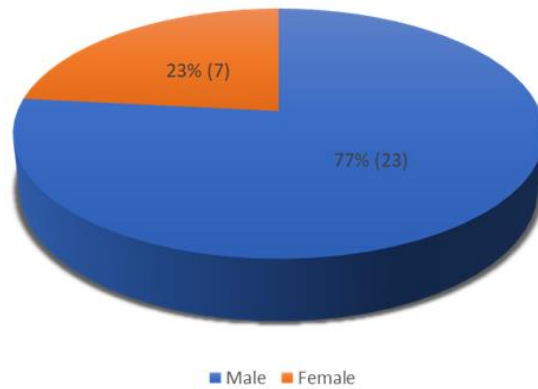
The first part of this chapter focuses on the profile of the respondents. These variables have been described in terms of age, sex, and educational attainment. The researcher used frequency and percentage, descriptive statistical tools in presenting the result.

Figure 2. Profile of the Respondents in Terms of Age



The statistical data reveals that the largest proportion of respondents (53.3%) falls within the 51 and above age group. Both the 29–39 and 40–50 age ranges each make up 23.3% of the sample, equivalent to 7 respondents for both ranges. Thus, the data shows a clear tendency toward an older demographic, with a total of 16 participants aged 51 and above. This result may imply that the farmers in Halang (Palangue) SPIS are well-experienced and knowledgeable in farming activities. However, it also highlights the need for knowledge transfer to the younger generation to ensure the continued management of the system.

Figure 3. Profile of Respondents in Terms of Sex



The figure above illustrates a notable gender distribution among the respondents, with males comprising a substantial majority. Specifically, 76.7% of the respondents are male, which corresponds to 23 out of the total 30 respondents. In contrast, females make up only 23.3% of the sample. This stark difference indicates a clear gender disparity within the group. The predominance of male respondents suggests that the population under study is heavily male-oriented. This likely reflects traditional gender roles in local farming.

Figure 4. Profile of Respondents in Terms of Educational Attainment

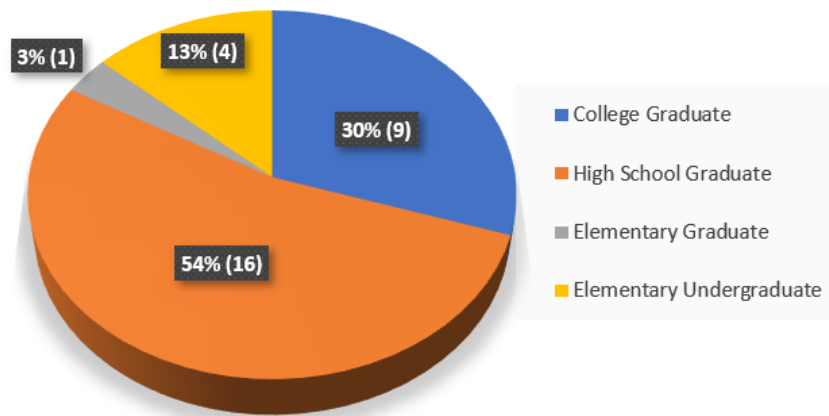


Figure 4 highlights the educational attainment of the respondents, revealing a diverse but uneven distribution. The majority of respondents, accounting for 53.3%, are high school graduates, indicating that more than half of the sample has achieved a basic level of secondary education. This is followed by college graduates, who comprise 30.0% of the respondents, suggesting a significant portion of the sample has attained higher education. Meanwhile, a smaller segment consists of elementary undergraduates (13.3%) and elementary graduates (3.33%), representing those with limited formal education.

The distribution indicates that most respondents have at least a high school education, suggesting a moderate to high level of educational literacy. This implies they are likely equipped with the cognitive and technological skills needed to adapt to new systems. Their educational background may also reflect basic digital literacy and problem-solving abilities, reducing the likelihood of resistance or difficulty during system implementation.

3.2. Organizational Capability

Tables 3 to 5 show the results of survey for the level of effectiveness of the Organizational Capability of Halang (Palangue) SPIP Irrigators Association (IA), in terms of Operation and Maintenance, Technology adaptation, and Risk Mitigation. Results from the above-mentioned variables will determine the readiness and capability of the Irrigators association in managing the SPIP including its appurtenant structures in the perspective of its members. Data were presented with mean score, standard deviation, and interpretation. These findings offer a comprehensive view of the Irrigators Association's strengths and areas for improvement in managing the Solar Pump Irrigation Project. By evaluating their performance in operation and maintenance, technology adaptation, and risk mitigation, the study highlights key factors that influence the association's overall readiness and capability. This information is crucial for identifying areas where the association may need improvement and for strengthening management strategies. Ultimately, it supports the long-term sustainability and success of the irrigation system.

This study used a quantitative approach with a survey method conducted using a Likert scale questionnaire with five alternative choices, namely, Extremely Effective (score=5), Very Effective (score=4), Moderately Effective (score=3), Slightly Effective (score=2) and Not at all effective (score=1).

Aside from the survey questionnaire, the researcher navigated an informal interview with the IA president and conducted site visit on the main source and other structures.

Table 3. Level of Organizational Capability in Terms of Operation and Maintenance

Indicator	M	SD	V.I.
1. The O&M of IA ensure that Solar Panels are always clean and no physical damage to maintain maximum efficiency.	5.00	0.00	EE
2. The O&M of IA regularly monitors the pump's flow rate for the early detection of any blockages or malfunctions in the system.	5.00	0.00	EE
3. The O&M of IA guarantees an equitable and timely water distribution among members.	4.87	0.43	EE
4. The O&M of IA conducts operation review and planning one month before the next cropping season.	4.93	0.25	EE
Overall for Operation and Maintenance	4.95	0.17	EE

Note. N=30. V.I. = Verbal Interpretation. The mean is interpreted as follows: 4.50-5.00= Extremely Effective (EE); 3.50-4.49 = Very Effective (VE); 2.50-3.49 = Moderately Effective (ME); 1.50-2.49 = Slightly Effective (SE); 1.00-1.49 = Not at all Effective (NE)

Table 3 demonstrates that the operation and maintenance system is extremely effective. Therefore, it can be concluded that the organization's (IA) Operation and Maintenance (O&M) practices are highly regarded for maintaining the proper functioning of its systems, including solar panels, pump monitoring, water distribution, and planning.

Table 4. Level of Organizational Capability in Terms of Technology Adaptation

Indicator	M	SD	V.I.
1. Farmers are given continuous training programs on solar irrigation practices, troubleshooting, and basic maintenance to ensure smooth operations and longer system lifespan.	4.93	0.25	EE

2. Adaptability to the changing weather patterns, water availability, and crop types to ensure efficiency of water management.	4.93	0.25	EE
3. Adopts and apply modern and proven farm techniques as may be suggested, taught, and directed by the government technicians.	4.83	0.46	EE
4. Farmer implements other water-saving practices such as drip irrigation, rainwater harvesting to maximize water conservation.	4.87	0.35	EE
Overall for Technology Adaptation	4.89	0.26	EE

Note. N=30. V.I. = Verbal Interpretation. The mean is interpreted as follows: 4.50-5.00= Extremely Effective (EE); 3.50-4.49 = Very Effective (VE); 2.50-3.49 = Moderately Effective (ME); 1.50-2.49 = Slightly Effective (SE); 1.00-1.49 = Not at all Effective (NE)

According to Guno & Agaton (2022), solar irrigation systems have no variable operational costs since they rely on sunlight instead of fuel. However, there are fixed maintenance costs, which cover labor, transportation, and the replacement of water pump which may take every 8 to 15 years, depending on several factors. The solar panels themselves require minimal maintenance, mainly consisting of regular cleaning to ensure optimal sunlight capture. In this regard, the consistently high ratings across all indicators reflect the organization's strong capability in managing its operations and maintenance tasks.

Table 4 indicates that the organization is highly proficient in implementing technological solutions. With mean scores ranging from 4.83 to 4.93 and minimal variability, all indicators are rated as Extremely Effective (EE). In general, the organization's efforts to adopt technology are regarded as very successful in enhancing water management, system performance, and supporting sustainable agricultural practices.

The survey results support the Technology Adaptation theory (Simon, 2011), which highlights the importance of technology in improving system performance and long-term sustainability. These innovations enhance flexibility to changing environment, optimize water use, and improve resource management. As agricultural needs evolve, solar pump systems become more adaptable, resilient, and capable of meeting the growing demands of modern farming, with farmers increasingly adopting them over traditional methods.

Table 5. Level of Organizational Capability in Terms of Risk Mitigation

Indicator	M	SD	V.I.
1. Availability of Battery that can store excess energy during the day for use at night or in bad weather.	4.90	0.31	EE
2. Presence of Water tanks where excess pumped water is stored as a back-up source.	4.93	0.25	EE
3. Availability of spare parts (such as pump components, valves, sensors, and batteries) to ensure prompt repairs of malfunctioning parts.	4.87	0.35	EE
4. Availability of Generator Set in case malfunction of Solar System.	4.97	0.18	EE
Overall for Risk Mitigation	4.92	0.23	EE

Note. N=30. V.I. = Verbal Interpretation. The mean is interpreted as follows: 4.50-5.00= Extremely Effective (EE); 3.50-4.49 = Very Effective (VE); 2.50-3.49 = Moderately Effective (ME); 1.50-2.49 = Slightly Effective (SE); 1.00-1.49 = Not at all Effective (NE)

Table 5 shows that the organization has implemented highly effective measures to ensure the reliability and sustainability of its systems. With mean scores ranging from 4.87 to 4.97 and low standard deviations, all indicators are rated as Extremely Effective (EE). Overall, the organization's risk mitigation

strategies are deemed highly effective, ensuring stable system performance and reducing potential disruptions. The consistently high ratings highlight a strong dedication to maintaining dependable and resilient operations.

High ratings confirm the recommendation from the study of Seguban (2016), where they recommended bigger size solar panels for more efficient charging, where excess energy will be stored on batteries for back up use. Same as inclusion of water reservoir or water tank as storage of excess pumped water, a water reservoir is essential for nighttime irrigation. Which shows the importance of these risk mitigation plans in the effectiveness of the system.

3.3. Community Benefit

Tables 6 to 8 show the results of survey for the level of Community Benefit of Halang (Palangue) SPIP to its beneficiaries, in terms of Cost Efficiency, Environmental Security, and Productivity. Data are presented with mean score, standard deviation, and interpretation. The findings provide valuable insights into how the solar pump irrigation system has contributed to reducing costs and promoting sustainable farming practices. Improvements in environmental security reflect the system's role in minimizing negative ecological impacts. Additionally, the increase in productivity demonstrates the direct benefits experienced by the farming community through enhanced water access and management. Overall, these results underscore the significant role of the SPIP in supporting both economic and environmental goals for the community. These outcomes affirm the potential of solar-powered irrigation as a viable and impactful solution for rural agricultural development.

This study used a quantitative approach with a survey method conducted using a Likert scale questionnaire with five alternative choices, namely, Extremely Effective (score=5), Very Effective (score=4), Moderately Effective (score=3), Slightly Effective (score=2) and Not at all effective (score=1). This scale allowed respondents to express varying degrees of effectiveness regarding different aspects of the Solar Pump Irrigation System.

Table 6. Level of Community Benefit in Terms of Cost Efficiency

Indicator	<i>M</i>	<i>SD</i>	<i>V.I.</i>
1. The use of solar pump irrigation systems helps increase farmers' income by reducing operational costs, as they rely on solar energy instead of electricity or diesel.	4.93	0.25	EE
2. Solar powered pump is low-maintenance and have fewer mechanical parts that can break down.	4.90	0.31	EE
3. Use of Solar Pump is a long-term investment for farmers, savings on electricity or diesel reduces the initial investment overtime.	4.90	0.31	EE
4. Batteries may be used to store excess energy to be used for other opportunity.	4.93	0.25	EE
Overall for Cost Efficiency	4.92	0.24	EE

Note. N=30. V.I. = Verbal Interpretation. The mean is interpreted as follows: 4.50-5.00= Extremely Effective (EE); 3.50-4.49 = Very Effective (VE); 2.50-3.49 = Moderately Effective (ME); 1.50-2.49 = Slightly Effective (SE); 1.00-1.49 = Not at all Effective (NE)

Table 6 shows that solar pump irrigation systems offer substantial cost-saving advantages for farmers. With mean scores ranging from 4.90 to 4.93 and minimal variation, all indicators were rated as Extremely Effective (EE). Overall, the solar irrigation system is considered a highly effective solution for minimizing costs and delivering lasting financial benefits to farmers, with the help also of the management

system of the organization, their best practices that makes the system efficient

The results are supported by the study, “Cost-Benefit Analysis between Solar-Powered and Diesel-fuel fed pumps in NIA-UPRIIS by Bencalo (2021), where he highlighted that the adoption of solar-powered pumps has proven to be both more efficient and cost-effective compared to diesel-powered pumps. With significant amount of savings from O&M cost over time. He even recommended the NIA to expand installation of Solar pumps to its project, since according to his study, this initiative would not only provide immediate environmental gains but also lead to significant long-term cost savings for the Philippine government.

Table 7. Level of Community Benefit in Terms of Environmental Security

Indicator	<i>M</i>	<i>SD</i>	<i>V.I.</i>
1. Solar powered irrigation promotes a climate-friendly and renewable source of energy.	5.00	0.00	EE
2. Solar powered pump reduces noise pollution.	5.00	0.00	EE
3. Utilizing solar power helps decrease greenhouse gas emissions.	4.93	0.25	EE
4. Usage of Groundwater as source and pipelines eliminates polluted water to irrigate the farmland.	5.00	0.00	EE
Overall for Environmental Security	4.98	0.06	EE

Note. N=30. V.I. = Verbal Interpretation. The mean is interpreted as follows: 4.50-5.00= Extremely Effective (EE); 3.50-4.49 = Very Effective (VE); 2.50-3.49 = Moderately Effective (ME); 1.50-2.49 = Slightly Effective (SE); 1.00-1.49 = Not at all Effective (NE)

Table 7 demonstrates that solar-powered irrigation systems offer significant environmental benefits. With mean scores ranging from 4.93 to 5.00 and minimal variation, all indicators were rated as Extremely Effective (EE). Overall, the solar irrigation systems are highly regarded for their positive impact on environmental security, reflecting their effectiveness in promoting sustainability and reducing environmental harm. These findings emphasize the system’s strong contribution to eco-friendly farming practices.

According to a study “Rethinking Energy” by IRENA (2015), the benefits of Solar Pump Irrigation System go beyond cost savings. These systems offer farmers energy independence, ensuring a reliable water supply in remote areas without access to the electrical grid. Furthermore, they contribute to environmental conservation. This finding is supported by Bencalo’s study (2021), which emphasizes the environmental benefits of using solar energy such as, they operate quietly, minimizing noise pollution, and eliminate the harmful emissions linked to diesel generators, leading to cleaner air and a healthier environment. These studies show Solar Pump as a clean, efficient, and sustainable farming solution.

Table 8. Level of Community Benefit in Terms of Productivity

Indicator	<i>M</i>	<i>SD</i>	<i>V.I.</i>
1. Sufficient water supply throughout the cropping season.	4.93	0.25	EE
2. Use of Solar pump help increase the amount of land available for irrigation, resulting to food sustainability.	4.97	0.18	EE

3. Solar pump can function without fuel or electricity and are particularly useful in remote areas especially for farmers that rely only on rainfed for irrigation.	4.93	0.25	EE
4. High Water Quality from the source & distribution line helps increase productivity.	5.00	0.00	EE
Overall for Productivity	4.96	0.13	EE

Note. N=30. V.I. = Verbal Interpretation. The mean is interpreted as follows: 4.50-5.00= Extremely Effective (EE); 3.50-4.49 = Very Effective (VE); 2.50-3.49 = Moderately Effective (ME); 1.50-2.49 = Slightly Effective (SE); 1.00-1.49 = Not at all Effective (NE)

Table 8 presents compelling evidence that solar-powered irrigation systems have a significant positive impact on agricultural productivity. The mean scores for all indicators range from 4.93 to 5.00, indicating a consistent perception among respondents that these systems are Extremely Effective (EE). These findings highlight the effectiveness of solar-powered irrigation in enhancing crop yields, ensuring more consistent water supply, and enabling farmers to cultivate their land more efficiently, even during dry seasons. Additionally, by reducing dependency on traditional fuel sources such as diesel, these systems contribute to lower production costs and environmental sustainability. Overall, the data strongly supports the conclusion that solar-powered irrigation systems play a crucial role in boosting agricultural productivity and promoting food security, particularly in regions reliant on small-scale farming. Their implementation not only empowers farmers economically but also aligns with broader goals of sustainable and climate-resilient agricultural practices.

The agricultural sector in the Philippines is predominantly composed of smallholder farmers, with 57% cultivating land of 1 hectare or less and 32% managing farms between 1 to 3 hectares (World Bank, 2021). This fragmented land distribution limits productivity and income, as farmers face challenges such as small landholdings, limited access to training, and restricted financing options. Inadequate irrigation, rising diesel costs, and climate change further exacerbate these issues, making it difficult for farmers to sustain their livelihoods. As a response, renewable energy technologies—such as solar-powered irrigation and biogas systems—are emerging as promising solutions. These innovations help reduce operational costs, lessen reliance on fossil fuels, and promote environmental sustainability, offering small-scale farmers a path toward increased productivity and resilience (Oakeshott, 2018).

Table 9. Correlations Between the Organizational Capability and Community Benefit

Organizational Capability	Community Benefit		
	Cost Efficiency	Environmental Security	Productivity
Operation and Maintenance	.88*** high corr. <.001	.83*** high corr. <.001	1.00*** very high corr. <.001
Technology Adaptation	.83*** high corr. <.001	.58*** moderate corr. <.001	.74*** high corr. <.001
Risk Mitigation	1.00*** very high corr. <.001	.71*** high corr. <.001	.86*** high corr. <.001

Note. Cell contains Spearman rank correlation coefficient, interpretation of its strength, and its corresponding p value. Degree of freedom is 28. Those with coefficient of 1.00 are rounded off to 1.00 but are actually less than 1.00.

* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 9 shows the Spearman rank correlation coefficients between organizational capability dimensions and community benefits. The correlations range from -1 to +1, with higher positive values indicating stronger relationships. Moreover, all the data presented is statistically significant, correlated at 0.05 level of significance where all the presented value of p is $< .05$.

The high positive correlations across all dimensions suggest that enhancements in organizational capabilities—such as operation and maintenance, technology adaptation, and risk mitigation—are strongly associated with improvements in community benefits, including cost efficiency, environmental security, and productivity. These findings underscore the importance of strengthening organizational practices to achieve sustainable and beneficial outcomes for the community. Improving organizational capabilities is therefore crucial for maximizing the system's overall impact.

This supports the systems theory, wherein it emphasizes the interconnectedness of components within a system, and how changes or enhancements in one part of the system can have ripple effects on other parts. In terms of interconnectedness, the high positive correlations between organizational capability dimensions and community benefits suggest that the organization and the community are interdependent parts of a broader system. Strengthening the organization's capabilities (inputs or components) leads to improvements in community outcomes (outputs or results), demonstrating the systemic nature of these interactions.

The significant statistical relationships suggest that enhancing organizational capabilities is not just a one-time effect but may lead to positive feedback loops. For example, better technology adaptation could lead to more efficient operations, which in turn might result in greater cost efficiency and productivity within the community. This enhanced community benefit may, in turn, support further organizational improvements, creating a continuous cycle of improvement in both organizational performance and community outcomes.

Therefore, the positive correlations between organizational capabilities and community benefits illustrate how systems, through their interconnected parts and feedback mechanisms, can produce more effective and sustainable results when each component (organizational capability) is optimized to support the broader system (community).

4. Summary of Findings, Conclusion, and Recommendations

4.1. Summary Of Findings

Solar-powered pump irrigation systems (SPIS) offer a sustainable and cost-effective solution, especially in solar-rich regions. This study assessed the effectiveness of the Halang (Palangue) Solar Pump Irrigation System in Naic, Cavite, focusing on operational performance, sustainability, and agricultural impact. Using surveys, interviews, and field observations, the research evaluated key indicators such as organizational capability and community benefits.

The survey yielded several salient findings. First, more than half of the respondents are aged 51 and above, with the majority being male. Second, the respondent group also reflects a diverse range of educational backgrounds, with a strong representation of individuals who have completed at least high school, suggesting a generally literate and adaptable population. Thirdly, in terms of the effectiveness of the Halang (Palangue) Solar Pump Irrigation System, results indicate that it is perceived as extremely effective, particularly in the areas of organizational capability and community benefit. This high level of effectiveness can be attributed, in part, to the good management and best practices employed by the Irrigator's Association overseeing the system. Lastly, the data demonstrate positive and statistically significant relationships between the organizational capabilities of the solar pump system and the benefits experienced by the community. The strength of these correlations ranges from high to very high across most variables, with the exception of the relationship between technology adaptation and environmental security, which, while still positive, shows a

moderate level of correlation. These findings collectively highlight the system's strong impact on agricultural and community development, as well as areas for further improvement.

4.2. Conclusions

Data gathered concludes that the demographic analysis of respondents indicates that over half are males aged 51 and above, with a diverse range of educational backgrounds. This diversity may contribute to varied perspectives on the effectiveness of the Halang (Palangue) Solar Pump Irrigation System. These differences can affect how the system is used and viewed.

The system's organizational capabilities—including operation and maintenance, technology adaptation, and risk mitigation—are evaluated as extremely effective. These practices align with recognized irrigation best management practices, emphasizing efficient water management, system design, and maintenance to achieve optimal performance. Positive and significant correlations between these organizational capabilities and community benefits—such as cost efficiency, environmental security, and productivity—underscore the system's impact. Notably, the correlation between technology adaptation and environmental security, though positive, is moderate, suggesting potential areas for improvement. These findings highlight the importance of continuous enhancement in organizational practices and technology integration to sustain and amplify the benefits of the Halang (Palangue) Solar Pump Irrigation System for the community.

Therefore, the null hypothesis is rejected, since results shows significant relationship between the Organizational Capability and Community Benefit of the Irrigators Association on the Halang (Palangue) Solar Pump Irrigation System of NIA.

4.3. Recommendations

Given that over half of the respondents are males aged 51 and above, the organization should implement targeted training and capacity-building initiatives to facilitate knowledge transfer and enhance management practices. These programs should be designed to promote continuous improvement through the collective input of all members, fostering harmonious relationships within the organization. Additionally, adopting community engagement strategies that encourage active participation from all demographic groups is essential. Ensuring that training programs are accessible and relevant to individuals with diverse educational backgrounds will support the development of a more inclusive and effective irrigation system.

During the site visit, it was observed that the solar panels exclusively power the water pump filling the storage tank. Once the tank reaches capacity, the system is manually shut off to prevent water wastage. To enhance efficiency, the Irrigators' Association (IA) could consider installing an additional water tank within their cooperative's greenhouse facility. This expansion would allow for increased water storage and utilization. Integrating batteries into the system would also provide backup power, ensuring continuous operation during periods of low sunlight, such as nighttime or cloudy days. This approach would optimize water and energy management, aligning with best practices in solar irrigation systems. Implementing these improvements could significantly boost the system's reliability and overall productivity for the farmers.

During the survey, the researcher had the opportunity to conduct informal interviews with the President of the Irrigators' Association (IA) and several members. It was observed that the IA employs a commendable approach in managing their irrigation system. Notably, they have installed individual meters at each member's outlet to accurately monitor water usage, ensuring that monthly dues are based on actual consumption, to promote fairness and transparency within the organization. To further enhance the effectiveness of Irrigators' Associations (IAs), the National Irrigation Administration (NIA) should incorporate sharing best practices from successful IAs into their training and capacity-building programs. Facilitating peer-to-peer learning and encouraging knowledge exchange among farmers through workshops

and field visits would allow them to share experiences and adopt effective strategies.

Acknowledgement

The author extends her deepest gratitude and appreciation to all the individuals and institutions who have played a significant role in making her academic journey both enriching and challenging throughout her time at the university.

She is especially thankful to the **Almighty God** for His unwavering love, abundant wisdom, and the strength that sustained her throughout this study;

Laguna State Polytechnic University – Santa Cruz Main Campus, her esteemed Alma Mater, for providing quality education and dedicated professors who have greatly contributed to her professional growth and development;

Honorable Dr. Mario R. Briones, EdD, University President, for his leadership in fortifying the foundation of the university and his commitment to fostering an institution that upholds academic excellence;

Dr. Eden C. Callo, internal statistician and chairman of the panel of examiners, for her unwavering dedication and invaluable support in maintaining the highest standards of education.

Dr. Mary Jane D. Fuentes, for her exceptional leadership in advancing the school's global competitiveness. Her strategic vision and unwavering commitment to excellence have inspired both faculty and students alike, and for being a constant source of inspiration;

Deep appreciation and gratefulness to **VPAA Atty. Rushid Jay S. Sancon**, for the valuable insights, providing brilliant ideas, and for the enormous guidance, all of which significantly enhanced this study;

Dr. Imee P. Sanchez, PhD, for her constructive comments, insightful suggestions, and valuable feedback, which greatly contributed to the refinement of this research;

The **NIA Cavite-Batangas Irrigation Management Office** especially to the Division Manager, **Engr Edwin C. Nazareno**, and his personnel for their generous assistance in gathering the essential data for this study;

Special recognition to **Mr. Roberto C. Mojica**, IA President of the Halang (Palangue) Irrigators' Association, for his warm welcome and willingness to share his knowledge, expertise, and experiences. His contributions were instrumental in helping the researcher better understand the system and formulate recommendations for its improvement.;

Gratitude is extended to the LSPU employees and the CBAA secretaries for their patience and unwavering support in all school-related activities;

To her fellow MPA classmates and friends for their valuable feedback, encouragement, and camaraderie throughout this journey;

Lastly, profound appreciation goes to her family—her husband, Neil Andrew, her daughters, Marian and Athena, as well as her parents and siblings—for their endless support, encouragement, inspiration, and prayers, which have been instrumental in the continuation and success of her study.

The Researcher

References

A. Books

- IRENA (International Renewable Energy Sources). Rethinking Energy. 2015. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA-_REthinking_Energy_2nd_report_2015.pdf
- Marciniak, A. (2024). Systems theory. In *Encyclopedia of Archaeology* (Second Edition). Elsevier. <https://www.sciencedirect.com/topics/social-sciences/systems-theory>
- The use of solar energy in irrigated agriculture. (2022). In *FAO eBooks*. <https://doi.org/10.4060/cb8459en>

B. Journals and other Publications

- Agaton, C. B., & Guno, C. S. (2024). Promoting sustainable agriculture using solar irrigation: A case study of small-scale farmers in the Philippines. United Nations Sustainable Development Goals Knowledge Platform. https://sdgs.un.org/sites/default/files/2024-05/Agaton%3B%20Guno_Promoting%20Sustainable%20Agriculture%20Using%20Solar%20Irrigation.pdf.
- Ahmed, N. M., Hassan, A. M., Kassem, M. A., Hegazi, A. M., & Elsaadawi, Y. F. (2023). Reliability and performance evaluation of a solar PV-powered underground water pumping system. *Scientific Reports*, 13(1). <https://doi.org/10.1038/s41598-023-41272-5>
- Aliyu, M., Hassan, G., Said, S. A., Siddiqui, M. U., Alawami, A. T., & Elamin, I. M. (2018). A review of solar-powered water pumping systems. *Renewable and Sustainable Energy Reviews*, 87, 61–76. <https://doi.org/10.1016/j.rser.2018.02.010>
- Alkhubaizi, I. & Miss. Nishigandha Kaneri.et.al. (2017). Solar water pump. *Int. Journal of Engineering Research And Application*, 5, 01–05. <https://doi.org/10.9790/9622-0705030105>
- Eker, B. (2005). Solar powered water pumping systems. *Trakia Journal of Sciences*, 3(7), 7–11. <https://www.researchgate.net/publication/268199675>
- Bencalo, C.E., Dela Cruz, R.D., Violago, D.B., Magtala, M.B., Aquino, C.S., Santos, M.D.: Cost benefit Analysis Between Solar-Powered and Diesel Fuel-Fed Pumps of the National Irrigation Administration Upper Pampanga River Integrated Irrigation Systems. *IJAEMS Article.2022*. https://ijaems.com/upload_images/issue_files/2IJAEMS-10220223-Cost.pdf
- Granić, A. (2023). Technology adoption at individual level: Toward an integrated overview. *Universal Access in the Information Society*, 23(2), 1–19. <https://doi.org/10.1007/s10209-023-00974-3>
- Guno, C. S., & Agaton, C. B. (2022). Socio-Economic and environmental analyses of solar irrigation systems for sustainable agricultural production. *Sustainability*, 14(11), 6834. <https://doi.org/10.3390/su14116834>
- Kazem, H. A., Quteishat, A., & Younis, M. A. (2021). Techno-economical study of solar water pumping system: optimum design, evaluation, and comparison. *Renewable Energy and Environmental Sustainability*, 6, 41. <https://doi.org/10.1051/rees/2021039>
- Majeed, Y., Khan, M. U., Waseem, M., Zahid, U., Mahmood, F., Faizan Majeed, Sultan, M., & Raza, A. (2023). Renewable energy as an alternative source for energy management in agriculture. In *Energy Reports* (Vol. 10, pp. 344–359). <https://doi.org/10.1016/j.egyr.2023.06.032>
- Merciales, J.R., Estacio, I.P., Ladores, C.S. Jr., Delos Santos, P.R., Padilla, A.A., Jocson, J.C.: Performance Assessment of Solar-Powered Irrigation Project in Nueva Ecija. 2022. <https://journal.ijprse.com/index.php/ijprse/article/view/738>
- Orpia, C., Orpia, J., & Liberato, M. (2021). Technical and economic analysis of solar photovoltaic water pumps against conventional systems in common crops in Ilocos Sur, Philippines. *Psychology and Education Journal*, 58(2), 1030–1039. <https://doi.org/10.17762/pae.v58i2.2132>
- Roblin, S. Solar-powered irrigation: A solution to water management in agriculture? *Renewable Energy Focus* (2016). <https://www.sciencedirect.com/science/article/abs/pii/S1755008416301065>
- Seguban, R.G., Seguban, C.M., Simon, A.R., Bumagat, E.M.: A Portable Solar-Powered Generating Apparatus for Irrigation System of Small Scale Farming “Tubig at Ilaw Mula sa Araw”. 2016. https://www.nvsu.edu.ph/assets/downloads/journal/vol3-1/NVSURJ_Vol.3_01_2016_3.pdf
- Ukoba, K., Yoro, K. O., Eterigho-Ikelegbe, O., Ibegbulam, C., Tien-Chien Jen, & The Authors. (2024). Adaptation of solar energy in the Global South: Prospects, challenges and opportunities. In *Heliyon* (Vol. 10, p. e28009) [Review article]. <https://doi.org/10.1016/j.heliyon.2024.e28009>
- Xie, H., Ringler, C., & Mondal, M. a. H. (2021). Solar or diesel: A comparison of costs for Groundwater-Fed irrigation in Sub-Saharan Africa under two energy solutions. *Earth S Future*, 9(4). <https://doi.org/10.1029/2020ef001611>

C. Unpublished Materials

- Food and Agriculture Organization of the United Nations (FAO). (2018). The Benefits and Risks of Solar-Powered Irrigation: A Global Overview. Rome: FAO. Retrieved from <http://www.fao.org/3/CA2672EN/ca2672en.pdf>
- Harvesting the sun: Challenges and opportunities in solar-powered agriculture | SNV. (n.d.). <https://www.snv.org/update/from-sunlight-to-growth-challenges-and-opportunities-in-solar-powered-agriculture>
- Khan, N., Xu, X., & Ahsan, F. (2024). Solar empowerment in agriculture: investigating photovoltaic energy’s impact on efficiency among wheat farmers. *Frontiers in Sustainable Food Systems*, 8. <https://doi.org/10.3389/fsufs.2024.1426538>
- Tanco, D. 2024: The Impact of Solar Water Pumps on Rice Production and Farmers in the Philippines. Blogs. <https://nativetechniks.com/benefits-of-solar-water-pumps-for-farmers/>

D. Electronic Sources

- Miwebdesigns. (2022, August 1). Common problems with solar water pumps – and some fixes - Walker Environmental. Walker Environmental. <https://wenv.com.au/water-pumps/common-problems-with-solar-water-pumps-and-some-fixes/>
- National Mapping and Resource Information Authority (NAMRIA). (2015). Land Cover of the Philippines. NAMRIA.
- NIA Public Affairs & Information Staff. 2023. NIA Intensifies Development of Solar-Powered Irrigation Projects.

- <https://www.nia.gov.ph/content/nia-intensifies-development-solar-powered-irrigation-projects>
- Solenergy Systems Inc. (n.d.). The many benefits of utilizing solar energy. (2025). <https://solenergy.com.ph/solar-panels-philippines-benefits-solar-energy/>
- World Bank. (2021). Transforming Philippine agriculture during COVID-19 and beyond. World Bank Group. <https://documents.worldbank.org/en/publication/documents-reports/documentdetail/336621614876694732/transforming-philippine-agriculture-during-covid-19-and-beyond>