Impact Assessment of the Government-installed Solar-Powered Irrigation Systems in Agusan del Sur

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Abstract: *This research examined the impact of Solar-Powered Irrigation Systems (SPIS) on small-scale farmers in Agusan del Sur, Philippines, using both quantitative and qualitative methods to assess economic, environmental, and social implications. Key findings included doubling rice production yield in San Francisco and Sta. Josefa during the dry season and a reduction in fuel costs from 69% to 34% after SPIS adoption. Beneficiary assessments in four municipalities showed varying satisfaction levels with SPIS usage and extension services, highlighting the crucial role of government agencies in boosting farmers' productivity and sustainable practices. SPIS implementation led to significant environmental benefits, including a reduction of 14,803.826 gallons of $CO2$ annually and decreased gasoline and diesel fuel consumption, saving approximately 181.774 and 1268.173 gallons per year. However, water misuse incidents pointed to the need for better measures and further education to ensure sustainable SPIS operation and maximize its benefits.*

Keywords: Solar-Powered Irrigation Systems; Impact Assessment; Agricultural Sustainability

1. INTRODUCTION

Agriculture is crucial for global growth and advancement, necessitating methodologies and technologies to ensure sufficient food production [1]. Effective irrigation management should consider the interconnectedness of energy, water, and food systems. Agriculture can supply renewable energy like biomass and biofuels, minimizing environmental impacts through sustainable energy sources. Solar energy, promoted by technological and governmental advancements, has become popular, particularly for water pumping, which is a cost-effective and environmentally friendly alternative to traditional systems.

The Solar Powered Irrigation System (SPIS) provides reliable, cost-effective energy, reducing irrigation costs and being especially beneficial in rural areas with expensive diesel fuel or unstable electricity grids [2]. SPIS, which uses photovoltaic cells to convert sunlight into electricity, aims to expand irrigable areas without relying on fuel or electricity.

The Philippines, with an average solar energy potential of 4.5 kWh/m² per day, is ideal for solar energy projects. The Department of Energy (PDOE) supports increased solar project integration; over 200 SPIS units have been completed nationwide [3]. In Camarines Sur, solar water pumping has increased rice yields and allowed better planting and harvesting planning. Implementing solar PV systems has improved irrigation efficiency, reduced costs, increased farmer earnings, and lowered CO_2 emissions [4]. Solar pumps, despite higher initial costs, offer lower long-term maintenance and operational expenses compared to diesel pumps [5].

However, the social sustainability of solar PV irrigation systems is a challenge involving public acceptance, social equity, and impact [6]. Adoption is influenced by perceived usefulness, ease of use, cost tolerance, awareness, and attitude [7]. Overcoming barriers such as inadequate policies, high investment costs, limited understanding, and insufficient infrastructure and skilled workforce is crucial for broader acceptance. Assessing the social, environmental, and economic impacts of solar PV systems is essential for sustainable development, enhancing community development, capacity, and social capital. Impact assessment aims to create a more sustainable and equitable environment.

2. METHODOLOGY

2.1 Process Flow

The researchers conducted a comprehensive study in the Caraga Region to identify the areas equipped with Solar-Powered Irrigation Systems (SPIS), gathered data from various government agencies, and conducted a thorough search for relevant studies to gain insights into the topic.

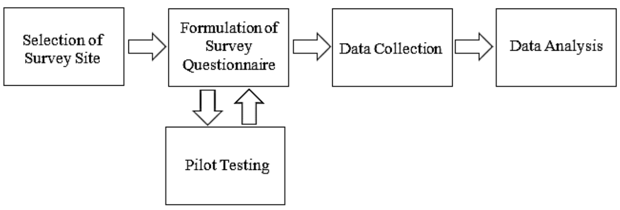

Fig. 1. General Framework of the Study

The researchers also formulated a survey questionnaire based on the research questionnaires used in related studies and conducted pilot testing in Brgy. Canaway, Kitcharao, and Agusan del Norte to ensure the questionnaire's effectiveness. The survey was conducted face-to-face and utilized individual interviews and focus group discussions as the techniques for data collection. Using a mixed-methods research approach, the researchers examined the characteristics of the installed SPIS and gathered demographic and socio-economic data from the beneficiaries. The collected data was summarized and analyzed using MS Excel software to calculate total and average values, establish frequencies, and create graphical representations.

2.2 Research Design

In this research study, a combination of quantitative and qualitative research methods was used to gain a more comprehensive understanding of the topic. The study was conducted in Agusan del Sur, a province in the Caraga Region, specifically in the four municipalities: Esperanza, San Francisco, Sta. Josefa, and Veruela, where the Solar-Powered Irrigation System was installed. The researchers opted to use the actual number of beneficiaries as respondents, due to the small number of beneficiaries enrolled in the program, the researchers were able to interview 30 farmers - three from Sinobong, Veruela, twelve from Pag-asa, Sta. Josefa, twelve from Oro, Esperanza, and three from Borbon, San Francisco. This approach ensured that the study was representative of the entire beneficiary population and provided valuable insights into the efficacy and impact of the SPIS program in Agusan del Sur.

Fig. 2. The study population (retrieved from Google Earth)

2.3 Characterization of the Solar-Powered Irrigation System

Researchers selected all sites within the province where SPIS was installed. Data was collected through on-site visits, interviews, and direct observations. The critical components of solar-powered irrigation systems were recorded. Operational practices and maintenance procedures followed by system operators were investigated. Stakeholder engagement with farmers, system operators, and other relevant parties provided insights into their experiences, challenges, and benefits associated with solar-powered irrigation systems.

2.4 Economic Impact Analysis of the Solar-Powered Irrigation System

The data collection process involved gathering data on crop yields, market prices, and other pertinent details required for the analysis. It also involved gathering information on crop yields before and after the implementation of the project. This determined if implementing the SPIS helped increase the rice production yield of the beneficiaries.

The researchers focused on the energy costs before implementing the SPIS. They identified the energy sources utilized in conventional irrigation systems, such as electricity, diesel, or gasoline. Subsequently, the energy consumption of the conventional irrigation system was determined, measured in units corresponding to the specific energy source employed (e.g., kilowatt-hours for electricity, liters, or gallons for diesel/gasoline). The cost per unit of the energy source utilized in the conventional irrigation system was also acquired (e.g., cost per kilowatt-hour for electricity, cost per liter/gallon for diesel/gasoline).

In addition, the impact on farm productivity and whether any increase in crop cycles was recorded.

2.5 Social Impact of the Solar-Powered Irrigation System

The social impact analysis of the SPIS was conducted by determining the user experience comprised of 5 subsections: awareness, usage, extension services, preferences, and knowledge. Another parameter used was determining any additional income streams, and this step aimed to investigate whether installing the SPIS helped the farmers diversify their income sources rather than relying solely on rice cultivation.

During field surveys, the farmers were interviewed to understand their satisfaction regarding the operation of SPIS, including fulfilling crop water requirements, yield using SPIS, and operating costs of SPIS. Another parameter was determining if there was an increase in opportunities after the installation of the SPIS, such as access to loans, crop insurance, training, and seminars. Lastly, researchers aimed to evaluate the post-implementation services that were available, the service provider, and the services being provided.

2.6 Environmental Impact of the Solar-Powered Irrigation System

In this study, the researchers compared the environmental impacts of solar and diesel irrigation systems in terms of GHG emissions, air pollution, and energy savings. To calculate the GHG emissions from using diesel-powered irrigation pumps, the total annual fuel consumption (FC) will be multiplied by the emission factor (EF) or its CO2 equivalent, as described in Equation (1) (Basic Information of Air Emissions Factors and Quantification, 2021).

$$GHG = FC \times EF \qquad (1)$$

Where: GHG= Greenhouse gases
FC= fuel consumption
EF= emission factor

For this study, FC equals the gallon of diesel used for irrigation in all cropping seasons of the year. At the same time, the EF is obtained from the Emission Factors for Greenhouse Gas Inventories as declared by the United Nations Development Programme (UNDP) in 2011 and the US Environmental Protection Agency (EPA) in 2021 (Basic Information of Air Emissions Factors and Quantification, 2021).

For air pollution, the researchers considered the compounds produced from the direct combustion of diesel and gasoline, including carbon monoxide, nitrogen oxide, sulfur oxide, and particulate matter. Carbon monoxide (CO) is a flammable gas that is odorless, colorless, and tasteless with a density slightly lesser than air but can cause poisoning when its concentration exceeds 35 ppm. Nitrogen oxide (NOx) is a highly reactive gas formed when fuel is combusted at a high temperature. Sulfur oxides (SOx) are a group of crucial ambient air pollutants, including gaseous and particulate chemical species such as sulfur monoxide, sulfur dioxide, sulfur trioxide, and disulfur monoxide. SO2 is emitted

from the combustion of fossil fuels and other industrial activities. Moreover, particulate matter (PM) is a complex mixture of hazardous particles formed from all the solid and liquid particles in the atmosphere composed of both organic and inorganic particles, such as dust, pollen, smog, soot, smoke, and liquid droplets.
For the calculation of air pollutant emissions (APEs), the total annual fuel consumption and pollutant factor were multiplied as shown in Equation (2):

$$APE_i = FC \times PF_i \tag{2}$$

Where:

APE= Air Pollutant Emission
FC= fuel consumption
i= air pollutant
PF= pollutant factor

Where i is the air pollutant (CO, NOx, SOx, and PM), and PF is the pollutant factor based on the conversions provided in the Emission Factors for Greenhouse Gas Inventories as declared by the Government of the Philippines, Department of Environment and Natural Resources (DENR) Environmental Management Bureau (EMB) (Basic Information of Air Emissions Factors and Quantification, 2021).
The researchers also aimed to identify whether the beneficiaries adopted specific measures or practices to ensure responsible and sustainable water use. The study conducted by EPA (2021) included this methodology to determine the water usage practices of the beneficiaries, seeking to understand the factors contributing to responsible water usage and identify replicable techniques for promoting sustainable water resource management.

3. RESULTS AND DISCUSSION

3.1 Demographic Profile of the Farmers in Agusan del Sur

Most of the workforce in the province was composed of male farmers, with 60% male respondents. This is expected because males do most farm operations like land preparation, seedbed preparation, and irrigation canal maintenance.

Table 1. Demographic profile of the beneficiaries

Variables	Distribution
Gender	
Male	60%
Female	40%
Age	
21-30	16%
31-40	17%
41-50	27%
51-60	33%
>60	7%
Educational Attainment	
Elementary Undergraduate	16%
Elementary Graduate	20%
High School Undergraduate	27%
High School Graduate	17%
Vocational	10%
College Undergraduate	7%
College Graduate	3%
Government Official/Employee	3%
Area Cultivated	
<1	10%
1-3	83%
3-5	7%

3.2 Characterization of the Government-Installed Solar-Powered Irrigation Systems in Agusan del Sur

To better characterize the SPIS, the researchers gathered data from the Department of Agriculture-Regional Agriculture and Engineering Division Caraga and considered the feedback from the beneficiaries.

Fig. 3. Components of the SPIS installed at Brgy. Pag-asa, Sta. Josefa, Agusan del Sur.
Source: DA-Caraga

Out of the four SPIS, two had not been operational for a year: those from Veruela and San Francisco. According to the beneficiaries in San Francisco, the submersible pump was damaged, while for the Veruela SPIS, both the pump and control panel were damaged.
On the other hand, the SPIS in Sta. Josefa and Esperanza were still operational and well-maintained, ensuring they were free from misuse or damage. However, all of the SPIS lacked batteries, which was one of the reasons why they could not pump water during rainy or cloudy days. Three of the SPIS used submersible pumps, while the one in Sta. Josefa used a surface pump.
Moving on to the specifications of each SPIS: for the Pag-asa, Sta. Josefa, the reservoir's dimensions are 9.84m in length, 9.83m in width, and 2.26m in height, made of reinforced concrete. The orientation of the 60 solar modules is southeast. For Oro, Esperanza, the reservoir's volume is 10 m³, and the pipes are made of Galvanized Iron. There are also 60 solar modules, which have an inclination angle of 6° with respect to horizontal. For Sinobong, Veruela, the 68 solar panels are inclined at 6° facing south. The outlet pipe is made of galvanized iron and is 152.4mm in size. Finally, for Borbon San Francisco, the 57 photovoltaic solar panels are inclined at 9° facing north. The water tank is made of concrete and has dimensions of 10m by 10m by 2m. The pipe is also made of galvanized iron and is 152mm in size.

3.3 Economic Impact Analysis of the Solar-Powered Irrigation Systems

3.3.1 Crop quantity (yield) and crop quality (cash)

The data in Table 2 indicates a significant increase in rice yield following the installation of the SPIS. Comparing rice production during the wet and dry seasons before and after the SPIS installation shows a substantial improvement in yield.

Table 2. Comparison of Rice Production Total Yield in Tons/Cropping, Agusan del Sur

	Rice Production (Tons/Copping)	
	Wet	Dry
Before (Installing SPIS)	37.27	31.43
After (Installing SPIS)	40.89	44.56

This suggests that the SPIS played a key role in boosting rice production. According to Bellini [8], farmers in Camarines Sur experienced notable yield increases, with some reporting up to 500kg per hectare per cropping and, in some instances, reaching a metric ton. This improvement was attributed to solar-powered irrigation systems, which helped farmers efficiently manage their planting and harvesting schedules to avoid adverse weather conditions. Additionally, research by Tamoor et al. [9] and Raza et al. [4] found that solar-powered and high-efficiency irrigation systems significantly enhance resource efficiency and crop yields, ensuring optimal water delivery to plants and benefiting farmers.

3.3.2 Energy cost and Energy savings

The data depicted in Table 3 provides a comprehensive analysis of the investment costs of Engines utilized by farmers in agricultural settings in Agusan del Sur prior to the implementation of the SPIS.

Table 3. Investment cost of Engines in Agusan del Sur

Engine Type	Value (Peso)
Diesel Engine	28,970.59
Gasoline Engine	11,000.00

The findings reveal that the Diesel Engine was the more popular choice among farmers, particularly in irrigation, with a total investment cost of 28,970.59 pesos. This preference for diesel engines can be attributed to their superior efficiency and durability compared to gasoline engines, as supported by the study by Banke-Thomas et al.[10],[11], which emphasizes the advantages of Diesel Engines in terms of emissions and performance. In contrast, the Gasoline Engines had a relatively lower investment cost of 11,000.00 pesos.

Notably, the more significant investment cost of the Diesel Engine was due to its superior efficiency and durability when compared with the Gasoline Engine. The farmers of Agusan del Sur were aware of these advantages, which contributed to the prevalent use of diesel engines in their farming activities.

Figure 4 presents the proportionate allocation of maintenance, fuel, and other operational expenses per annum prior to the implementation of SPIS.

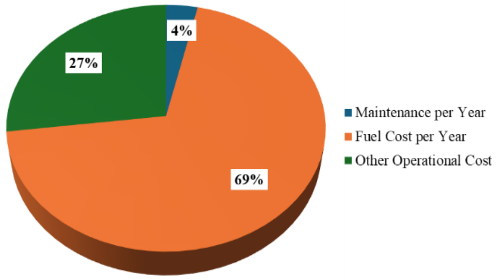

Fig. 4. Percentage Distribution of Maintenance, Fuel, and Other Operational Costs per Year (Before SPIS)

As per the survey, 69% of the total cost is fuel expenses because the farmer only relies on conventional pumps to irrigate their areas during the dry season, while a lower percentage uses them during the wet season. At the same time, 27% is allocated for other operational expenses, which include Land Preparation, Crop Establishments, Crop Care, Harvesting, and others. Only 4% is spent on maintenance per year for traditional pumps.

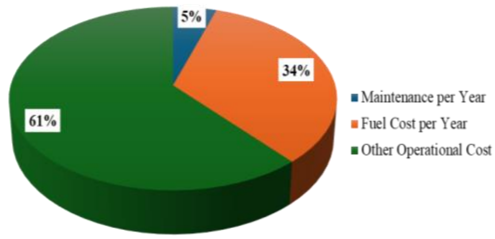

Fig. 5. Percentage Distribution of Maintenance, Fuel, and Other Operational Costs per Year (After SPIS)

Figure 5 illustrates the Percentage Distribution of Maintenance, Fuel, and other Operational Costs per year after the implementation of SPIS. Most of the costs incurred after the implementation of SPIS fall under operational costs, accounting for 61% of the total costs. Fuel cost per year constitutes 34% of the total cost, while only 5% of the cost incurred per year is attributed to Maintenance of the traditional pumps. After implementing a SPIS, there was a noticeable shift in the cost distribution, as indicated by financial records. The percentage of fuel costs decreased from 69% to 34%, which can be attributed to the optimization of fuel consumption facilitated by the system. This optimization likely led to more efficient fuel usage and cost savings. Conversely, operational costs increased from 27% to 61% post-SPIS implementation. This rise in operational costs could be due to factors such as inflation and the impact of the COVID-19 pandemic [12]. The increase in operational costs highlights the importance of considering external factors that can influence cost dynamics in post-implementation financial analyses.

Table 4 highlights the fuel consumption patterns in various municipalities before and after installing Solar-Powered Irrigation Systems (SPIS). Initially, fuel consumption was higher during the dry season, with 53.33% of beneficiaries using traditional pumps due to low water availability, compared to 43.33% during the wet season. After installing SPIS, fuel consumption dropped significantly, from 82 liters to 35 liters in the dry season and 50 liters to 18 liters in the wet season.

Table 4. Comparison of Fuel Consumption Before and During the Operation of SPIS in litters

	Fuel Consumption (L)	
	Wet Season	Dry Season
Before (SPIS)	50.00	81.64
During (SPIS)	17.75	35.38

This shift occurred as farmers primarily relied on SPIS, using traditional pumps only as supplementary energy sources. SPIS, powered by solar energy, is more efficient and cost-effective, reducing fossil fuel consumption and providing a more environmentally friendly solution, particularly in areas with high solar radiation [13] [14].

Table 5. Comparison of Fuel Cost Before and During the Operation of SPIS Fuel Cost in Peso

	Fuel cost (Php)	
	Wet Season	Dry Season
Before (SPIS)	8,791.67	13,083.33
During (SPIS)	5,125.00	7,075.00

According to the data presented in Table 5, the fuel cost per farmer was quite high before the installation of the Solar-Powered Irrigation System (SPIS). On average, each farmer had to spend approximately 8800 pesos on fuel to irrigate their fields before the operation of SPIS in the wet season. However, after installing SPIS, the fuel cost per farmer was reduced significantly to only 5125 pesos, representing a remarkable decrease.

This reduction in fuel cost has been an excellent development for farmers, as it has saved them approximately 3,700 pesos per person while using SPIS for irrigation in the wet season. This considerable saving has contributed significantly to the farmers' financial stability, allowing them to reinvest their resources in their farming activities or improve their livelihoods. Although the initial investment for a solar pump may exceed that of a diesel-powered generator, the lower maintenance and absence or lesser fuel costs make a solar power system a potentially more cost-effective choice in the long term [5].

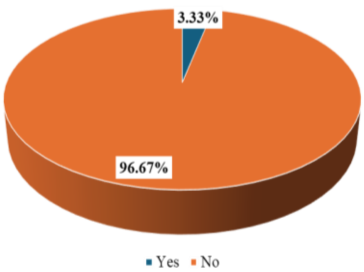

Fig. 6. Change in the frequency of the planting cycle for rice.

Based on the response of the beneficiaries of the SPIS there has been no change in the area allocated to different crops since the implementation of SPIS, indicating that all existing crops have remained unchanged.

However, 3.33% of the respondents reported a change in the frequency of planting cycles for specific rice. This change is due to farmers utilizing the water available in their fields, even outside traditional season for planting crops. This suggests that while the overall crop distribution remained stable, some farmers adapted their practices in response to the availability of water facilitated by the SPIS. These adjustments could be attributed to the newfound ability of farmers to utilize water resources for planting even outside traditional seasons, leading to changes in planting cycles and crop selection strategies [15].

3.3 Social Impact Analysis of the Solar-Powered Irrigation Systems

3.3.1 User Experience

The evaluation of the user experience of SPIS beneficiaries encompassed an assessment divided into five subsections.

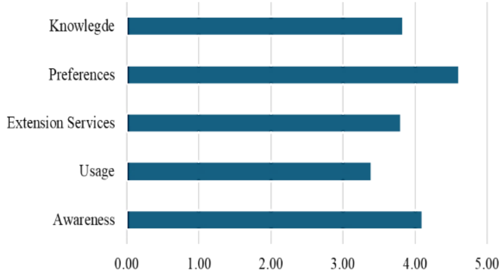

Fig. 7. Distribution of user experience of SPIS beneficiaries

Firstly, the awareness category revealed beneficiary scores ranging from 4.09, signifying a strong understanding of the SPIS's agricultural benefits, water distribution, and local information dissemination. This suggests a positive comprehension of the system's advantages [10],[16]. Secondly, the usage of Solar-Powered Irrigation Systems (SPIS) in different municipalities yielded varying impacts on beneficiaries, with an average score of 3.38, moderately indicating the ease of using SPIS. This suggests challenges in using SPIS for various purposes and questions its reliability in providing consistent irrigation.

The evaluation also scrutinized the extension services provided by the implementing agency, measuring beneficiary satisfaction post-SPIS implementation. Satisfaction levels varied significantly across different locations, with high satisfaction in Esperanza and Sta. Josefa and dissatisfaction in San Francisco and Veruela. Overall, the beneficiaries scored 3.79 for extension services, indicating agreement on the quality of services, including complaint resolution and maintenance promptness, which significantly influenced beneficiary satisfaction levels.

Preferences were the fourth category, measuring beneficiaries' willingness to invest in SPIS, with preferences scoring the highest at 4.60. Understanding beneficiaries' preferences and willingness to invest in SPIS is crucial for successful adoption. Furthermore, beneficiaries' knowledge about the benefits of SPIS, such as increased crop yield and cost savings, is essential for investment decision-making [10]. The overall beneficiary score was 3.82.

3.3.2 Additional Income Streams

The beneficiaries were unable to sell the water to neighboring farms or communities due to the absence of excess water, as their water usage was already regulated by a predetermined schedule. This restriction meant that they were unable to tap into the potential market for selling water to others, which could have been a lucrative source of income. However, the data indicated that a small percentage of beneficiaries (6.67%) in Oro, Esperanza, and Sta. Josefa was able to utilize the water for fish farming, presenting a potential income stream for some. Additionally, a small percentage (3.33%) of beneficiaries in San Francisco managed to use the water for cultivating cucumbers, demonstrating diverse agricultural utilization of the available water resources. SPIS allows farmers to diversify their agricultural activities beyond traditional crops, opening new income opportunities. It also provides inexpensive, reliable, and sustainable energy for irrigating crops like rice, corn, and high-value crops [17].

3.3.3 Farmer's Satisfaction

Figure 8 details the satisfaction levels of farmers utilizing SPIS, with the highest rating of 4.50 for effectively meeting crop water requirements.

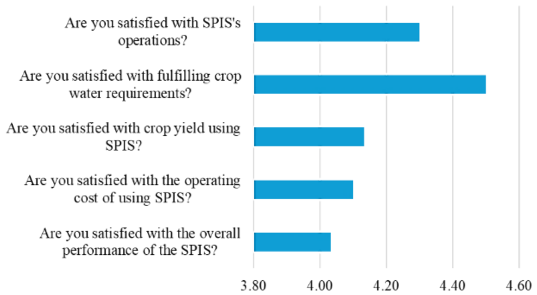

Fig. 8. Satisfaction levels of SPIS Beneficiaries

All sub-parameters, reflecting various aspects of farmer satisfaction, scored between 4.03 and 4.05, indicating overall satisfaction with SPIS operation, crop yield, and operating costs. The adoption of solar-powered irrigation systems (SPIS) is increasingly favored by farmers due to their economical and eco-friendly benefits [18].

3.3.4 Increase Opportunities

To assess the impact of Solar Powered Irrigation Systems (SPIS) in Agusan del Sur on beneficiary opportunities, it is crucial to analyze the effects on access to various services. A small percentage of beneficiaries (6.67%) gained access to finance and certification programs through SPIS, while only 10% utilized land titling services. However, approximately 70% reported accessing crop insurance, which is vital for safeguarding crops from risks This supports the idea that improving access to risk-mitigating services like crop insurance can enhance the sustainability and resilience of small-scale farming activities [19],[20]. Additionally, 16.67% received renewable energy credits, helping reduce energy costs and contribute to a cleaner environment.

The data indicates that while access to finance, certification programs, and land titling services remains limited, the rise in crop insurance uptake demonstrates a positive outcome of the SPIS initiative, underscoring the importance of tailored agricultural engineering strategies to boost productivity and address small-scale farmers' specific needs [21]. The participation rate in training and seminars related to SPIS is about 60%, which is essential for enhancing beneficiaries' ability to utilize SPIS effectively and gain knowledge in sustainable crop production practices [22].

3.3.5 After-implementation Services

Beneficiaries were aware of SPIS benefits and preferred it over traditional energy sources. However, scores for usage, extension services, and preferences varied significantly across the four municipalities. Some beneficiaries had positive experiences, while others were less satisfied with the after-implementation services.

Table 6. After-implementation Services received by the beneficiaries

Variables	Distribution
Numbers of Beneficiaries Received After-implementation Services	
Yes	93%
No	7%
Government Agencies that provide After-Implementation Services	
DA-RAED	93%
MAO	37%
After-Implementation Services Provided to SPIS Beneficiaries	
Seminars related to SPIS	87%
Updates about agricultural-related activities	9%
Provision of agricultural materials	4%

The study also found that while some beneficiaries could generate additional income from SPIS, most faced limitations due to location and resource access. Additionally, the DA-RAED Caraga and Municipal Agriculture Offices played a crucial role in providing after-implementation services, positively impacting farmers' productivity, income, and adoption of sustainable agricultural practices.

3.4 Environmental Impact Analysis of the Solar-Powered Irrigation Systems

3.4.1 Reduction of GHG Emissions and Air Pollutants

In terms of the environmental impact of using the Solar-Powered Irrigation System (SPIS), the results are quite promising. According to the data, the overall reduction in greenhouse gas (GHG) emissions from the four municipalities after utilizing SPIS as the energy source for irrigation is 14,803.826 gallons of CO_2 per year. This significantly reduces GHG emissions, which contribute positively to the environment. Solar-powered irrigation systems have garnered considerable attention for their potential to decrease CO_2 emissions and offer sustainable irrigation solutions. These systems utilize solar energy to operate irrigation pumps, diminishing reliance on fossil fuels and curtailing greenhouse gas emissions [23].

Table 7. Reduction of GHG Emissions in Agusan del Sur

Municipality	GHG emission reduction (gal/year)
Esperanza	2017.723
San Francisco	4402.304
Sta. Josefa	7499.022
Veruela	884.777
Total	14803.826

Apart from reducing GHG emissions, SPIS has also helped avoid other pollutants. For instance, the use of SPIS has helped to avoid 0.399 tons per year of carbon monoxide, 0.357 tons per year of nitrogen oxides, 0.024

tons per year of sulfur oxides, 0.025 tons per year of particulate matter, and 0.040 tons per year of volatile organic compounds.

Table 8. Reduction of Air Pollutants in Agusan del Sur

Municipality	Avoided Pollutants (ton/year)				
	Carbon monoxide	Nitrogen oxides	Sulfur oxides	Particulate matter	Volatile Organic Compound
Esperanza	0.012	0.054	0.004	0.004	0.004
San Francisco	0.026	0.118	0.008	0.008	0.010
Sta. Josefa	0.335	0.163	0.011	0.011	0.024
Veruela	0.027	0.021	0.002	0.001	0.002
Total	**0.399**	**0.357**	**0.025**	**0.024**	**0.040**

This is a remarkable achievement, as the reduction in these pollutants significantly impacts the environment. Research indicates that solar irrigation systems can substantially diminish greenhouse gas (GHG) emissions and air pollutants like carbon monoxide, nitrogen oxides, sulfur oxides, and particulate matter by reducing dependence on traditional diesel-powered pumps, which contribute to air pollution. Solar-powered irrigation systems aid in mitigating climate change and cutting down carbon dioxide emissions [24]. Research indicates that both long-term and short-term exposure to these air pollutants affects human health in various ways, leading to respiratory and cardiovascular diseases, neuropsychiatric issues, eye and skin problems, as well as long-term chronic conditions like cancer. As a result, substituting conventional irrigation systems with SPIS helps prevent air pollution caused by fuel combustion, thereby lowering the health hazards for farmers and local communities.

Furthermore, the use of SPIS has helped farmers save energy. Farmers have reduced gasoline fuel consumption by approximately 181.774 gallons per year and diesel consumption by 1268.173 gallons per year. This energy savings is not only an environmental win but also a financial gain for the farmers, as it reduces their energy bills and increases their profitability.

3.4.2 Judicious or indiscriminate use of water by the beneficiaries

Figure 9 illustrates water usage in Agusan del Sur, revealing that all respondents used the solar-powered irrigation system (SPIS) to schedule water, conserving it by using the system at specific times of the day. Among the respondents, 23.33% stated that their SPIS includes a tracking and monitoring system to identify water usage patterns and detect leaks or malfunctions for prompt repairs [25].

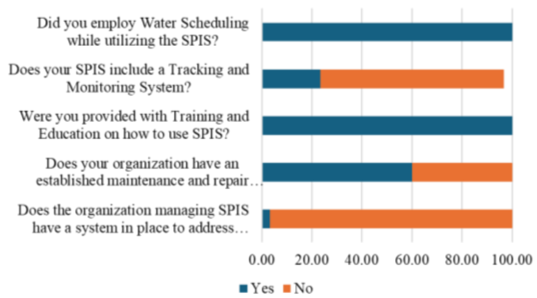

Fig. 9. Usage of Water from the SPIS Beneficiaries

All respondents received training on operating the SPIS, covering water scheduling, leak detection, and maintenance. Additionally, 60% reported having a maintenance and repair system to address issues efficiently. However, only 3.33% had a system to address water misuse or overuse, indicating a need for more education and effective measures to manage water resources properly.

4. CONCLUSIONS

Out of the four SPIS, two in Veruela and San Francisco have not been operational for a year due to damage to the submersible pump and control panel, while those in Sta. Josefa and Esperanza function well but lack batteries, affecting performance during cloudy or rainy days. Economically, SPIS installations have substantially increased rice yields, which is especially notable in Sta. Josefa and San Francisco. Even though Esperanza saw a slight decline in wet-season yield, dry-season yields improved significantly. Diesel engines were previously favored for their efficiency, with fuel costs comprising 69% of expenses. Post-SPIS implementation, fuel costs dropped to 34%, highlighting significant cost savings.

Despite no change in crop area allocation post-SPIS, some farmers reported increased planting cycles for rice. User experience varied; while all beneficiaries preferred SPIS over traditional methods and were aware of its benefits, satisfaction scores differed among municipalities, particularly concerning after-implementation services. Some beneficiaries generated additional income streams from SPIS, but many-faced limitations due to location and resource access. Nonetheless, farmers reported high satisfaction with SPIS operation, crop yield improvement, and cost reduction, demonstrating the system's effectiveness in meeting crop water needs and overall contentment.

SPIS's environmental benefits include a significant reduction of CO_2 emissions by 14,803.826 tons annually, along with decreased emissions of other pollutants like carbon monoxide, nitrogen oxides, sulfur oxides, particulate matter, and volatile organic compounds. This has contributed to environmental preservation and reduced gasoline and diesel consumption, leading to cost savings. The study also highlighted the judicious use of water through SPIS scheduling, although a small percentage of respondents lacked measures to address water misuse, indicating a need for improved water management awareness and practices.

The involvement of DA-RAED Caraga and Municipal Agriculture Offices has been pivotal in supporting agricultural beneficiaries through training, updates on agricultural activities, and provision of resources. This active role underscores the agencies' commitment to enhancing farmers' skills and knowledge. The SPIS initiative has not only provided environmental benefits but also bolstered the sustainability and resilience of small-scale farming in the region through increased access to crop insurance, renewable energy credits, and training opportunities despite the limited access to finance and certification programs.

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