Propelling Rural Communities: The Impact of Solar-Powered Irrigation Systems

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Abstract*— The study aims to assess the impacts of solar-powered irrigation systems on farmers with varying demographic characteristics, including age, gender, education level, and farm size, in Guimba, Nueva Ecija; particularly focusing on its socio-economic impacts, environmental impacts, technical and operational feasibility, and social and institutional factors based on their collective insights and perceptions throughout the implementation and utilization of the irrigation system as its principal beneficiaries. The research employed a mixed-methods approach, combining quantitative and qualitative data collection techniques. Among key findings incorporate community impact, water usage and quality, soil health, irrigation water reliability, operation and maintenance, knowledge and awareness, and government interventions. However, challenges such as technical limitations and assistance from agricultural extension services of any government institution or irrigation agencies were also identified. To maximize the benefits of solar irrigation, recommendations are provided, including the implementation of targeted subsidies or low-interest loans to farmers, provision of comprehensive training on solar irrigation systems, further development of reliable power distribution networks for solar irrigation systems, upgrading of research and development toward its improvement, reinforcing farmer organizations, augmentation of solar irrigation initiatives, and establishment of a resilient regulatory framework. By addressing these concerns, the study advances knowledge of solar irrigation's potential to improve rural livelihoods and agricultural sustainability.

Indexed Terms*— Solar-powered Irrigation, Solar Energy, Rural Development, Agricultural Productivity, Sustainable Agriculture, Climate Change Mitigation

I. INTRODUCTION

The continuous swelling of global population entails the surge of demand for food and water now posing a threat of widespread scarcity as impacts from climate change emerges to this day. As frontliners for food production, farmers in many rural and far-flung areas depends significantly on reliable and accessible source of irrigation water towards their farmlands. While most of them already utilize diesel-powered pumps, which can be costly and environmentally harmful; still, some can't really sustain such mechanism thus lean on gravitational flow of irrigation network directly to their areas.

An innovative groundbreaking of solar-powered irrigation systems addresses these challenges that harness solar energy to pump water from water sources to fields, offering a sustainable and cost-effective alternative to traditional methods. Not only this reduces reliance on fossil fuels, it also caters dependable water supply further marking substantial outcomes to augmenting agricultural productivity; thereupon upgrading livelihood of the people from the community yet conforming to environmental sustainability.

Despite progressive efforts to establish and venture with solar-powered irrigation systems with remarkable potential benefits contemplated, various factors including high initial costs, technical complexities, and limited access to financing obstruct further advancement and adoption. It is critical to gauge the impacts of having solar-powered irrigation systems

established within far-reaching, tail-end portion of currently existing irrigation network areas to align with adjustments and considerations prerequisite to further expansion and replication as part of community extension services, benefiting more people in the future.

The research endeavors to analyze the impact of solar-powered irrigation systems on rural communities in Guimba, Nueva Ecija. Specifically, it aims to assess how these systems promote to strengthen agricultural productivity, improve water management, reduce reliance on fossil fuels, and contribute to socio-economic development by empowering rural communities, creating jobs, and reducing greenhouse gas emissions, ultimately reducing poverty and promoting sustainable development.

II. REVIEW OF RELATED LITERATURE

Bencalo et al. (2022) conducted a study aimed to compare the use of solar-powered pump as against the conventional diesel fuel-fed pump in terms of installation and maintenance costs in which they have concluded that based on the findings of the study, the use of solar-powered pump is more efficient and cost-effective than the use of diesel-powered pump. It is also estimated a savings of approximately Php 277,028,649.18. Furthermore, solar-powered pump reduces noise pollution and eliminates the harmful effects of gas emission from diesel fuel-fed generators. The researchers also recommended that more solar-powered pumps be installed by the agency for all its irrigation projects as this would result in big savings in the long term for the Philippine government.

In a study administered by Raza et al. (2022), entitled: "The Socio-Economic Impact of Using Photovoltaic (PV) Energy for High-Efficiency Irrigation Systems: A Case Study", it has been concluded that photovoltaic systems operating high-efficiency irrigation systems (HEIS) can provide clean, climate-smart, and innovative energy technologies for efficient irrigation systems in remote areas (especially areas that are not connected to the national utility grid or conventional power sources); this can bring huge socio-economic and environmental benefits. In countries with water shortages, especially in desert areas, PV-powered HEIS helps to stabilize and increase crop production and reduce the impact of drought, in order to overcome the pressure of water shortages in the dry season. PV-powered HEIS will encourage farmers to grow high-value crops such as orchards and vegetables, which will help to reduce poverty in remote areas.

A study aimed to analyze and evaluate the dependency of the cumulative primary energy demand (CED) and the related emissions, energy and carbon payback periods (EPBT and CPBT) and energy return on investment (EROI) on the size of the Photovoltaic Irrigation Systems (PVIS) and on other factors like the water needs of the cultivated crops and the water availability. lead by Todde et al. (2018) provided evidence of the energy and environmental benefits obtained through the use of stand-alone PVIS. The energy life cycle assessment highlighted the main significant phases that contributed most to the consumptions of primary energy and to the environmental emissions of CO2e. In fact, emissions into the atmosphere mainly occur using primary energy during the manufacturing process of photovoltaic modules (about 80%), while the maintenance of the PV systems was negligible.

More significantly, Lamine (2020), in a study entitled: "Technical and Economic Feasibility of Solar Irrigation Pumping System: A Review", further substantiated that solar energy is considered a promising alternative energy source to conventional energy sources. Conventional energy sources such as fuel and electricity can be considered as inhibiting factors to the development of irrigation. These energy sources are most often used for water pumping. However, they are very expensive, and electricity is not always accessible, especially in rural areas. Various factors impact on the operation of solar pumps, among them the most important is solar irradiation. The different works carried out on solar pumping show that they can be used in many places in the world.

Additionally, it also justified that the use of solar irrigation pumps is economically feasible, despite the high investment cost, perceived as a limiting factor to its adoption. In addition, the various studies show that the investment cost decreases over time due to the significant decrease in the cost of the panels and even the pump which promotes the use of solar energy for

water pumping. A special feature of solar irrigation pumps is related to their low environmental impact. In general, the CO2 emissions related to solar pumps occur during the manufacturing and destroying of the solar panels. However solar pump doesn't have environmental impact during operation in contrast to diesel or electrical pumps. In addition, more in-depth studies ca be carried out on solar pumping.

Conclusively, Guno (2024) in her study entitled: "Diesel to Solar Irrigation System: Economic, Environmental, and Social Acceptability Analyses by Small-Scale Farmers of Calapan, Oriental Mindoro", supported that using renewable energy benefitted the community by enhancing food security, economic well-being, and ecological sustainability, while reducing agriculture's negative impact on local ecosystems and the global environment. Her study further analyzed the feasibility of shifting irrigation systems from fossil fuels to renewable energy to realize these benefits. The novelty of this study highlighted the perspective of financially disadvantaged farmers of small-scale farms in Calapan City, Oriental Mindoro. It analyzed the economic attractiveness, environmental impact, and social acceptability of shifting irrigation technology from diesel-powered to solar pump systems.

Moreover, she discussed that the parameter estimation showed that solar irrigation systems are more expensive than their diesel counterpart in terms of initial investment. However, its maintenance and operational costs are relatively lower. Hence, farmers could save on fuel costs for the rest of their lives. Given the volume of diesel used by farmers per hectare, results demonstrated that by shifting to solar PV, a significant amount of carbon dioxide and other air pollutants could be kept from interspersing in the air. Using the volume of agricultural consumption of diesel and the country's annual fuel demand, shifting to solar PV systems to irrigate rice farms can significantly increase the energy savings of the agricultural sector.

Rural communities, forging the landscape of a first-class municipality in Nueva Ecija, the municipality of Guimba, constantly encounters significant challenges in accessing dependable and accessible water resources for irrigation mainly in far-flung areas and tail-end portions of the existing irrigation network. This study intends to assess the impact of solar-powered irrigation systems currently established on rural communities within this chosen area, focusing on their socio-economic and environmental benefit. Specifically, it aims to answer the following, to wit:

1. Socio-economic Impact:
- What is the impact of solar-powered irrigation systems on the total annual income of the farmers in Guimba, Nueva Ecija?
- How these solar-powered irrigation systems affect the farmers' quality of life?
- What perceptions do farmers have on the benefits of solar-powered irrigation systems in the community?

2. Environmental Impact:
- What effects does solar irrigation have on water efficiency?
- What is the current perspective of farmers on the quality of the water source drawn out from the solar-powered irrigation systems?
- How farmers view the impact of solar-powered irrigation systems on soil health?

3. Technical and Operational Feasibility:
- How farmers assess reliability on solar-powered irrigation system in terms of providing water to their crops?
- What are the farmers' views on the ease of operation when it comes to the solar-powered irrigation system on a daily basis?
- How the farmers apprehend the necessity to perform maintenance on the system based on the distinguished assessment of its operation?

4. Social and Institutional Factors:
- How the farmers perceive community involvement and social acceptance on the establishment and installation of these solar-powered irrigation systems?
- What proportion of farmers presents the level of their knowledge and awareness on the establishment and installation of the solar-powered irrigation systems in the community?
- What is the extent of government interventions based on the farmers' collective insights on the

implementation of solar-powered irrigation systems within their communities?

The study was conducted in Guimba, Nueva Ecija within Region III/Central Luzon across its 245.29 square kilometers land area comprising the 64 barangays to which respondents of different areas mostly benefitted by the solar-powered irrigation systems were being assessed based on their perceived impacts and obtained effects since its implementation.

The study on the assessment of the impact of solar-powered irrigation systems on rural communities holds significant implications for legislators, irrigation agencies, development authorities and rural communities themselves. As for rural communities that involves the livelihood of farmers and members of the community, solar-powered irrigation systems boost agricultural productivity, improve food security, and reduce reliance on diesel-powered water pumps in rural communities, thereby reducing poverty and enhancing living standards and reducing operating costs.

The study was also substantial to legislators, irrigation agencies, and development authorities inasmuch as the research can guide them in developing effective solar-powered irrigation systems, tailoring interventions to rural communities' needs, and prioritizing investments in solar technologies and infrastructure. The research contributes to sustainable agriculture and renewable energy technologies, inspiring further research on solar irrigation systems. Understanding socio-economic and environmental impacts can accelerate adoption and improve rural livelihoods by legislators, irrigation agencies, and development authorities, and researchers.

III. METHODOLOGY

A. Research Design

The study incorporates a mixed methods research design combining a quantitative and qualitative methods to provide a comprehensive understanding of the given phenomenon. As for the employment of quantitative component, the study utilized survey data delivered by closed-ended questions to collect data on demographics and farmer's perspectives that further estimated the frequency, types, and significance of the implemented solar-powered irrigation systems, as well as their perceived impact on various aspects in terms of socio-economic and environmental impact, technical and economic feasibility, and social and institutional factors. Meanwhile, the qualitative component is being reflected on the gathered collective insights and perspectives on the implementation of solar-powered irrigation systems as well as its contribution, effects, and benefits to agricultural production. This scrutinized the in-depth experiences and perceptions of farmers regarding solar-powered irrigation systems.

Quantitative methods presented numerical data for statistical analysis, whereas qualitative methods forwarded substantial insights into participants' experiences. Combining both approaches enhances the validity and reliability of the findings by establishing evidence from multiple sources. Qualitative data contributed to help explain the underlying reasons for the quantitative results, providing a more elaborated interpretation.

The study formulated specific research questions to guide the data collection and analysis. It then classified the target population of farmers and selected a representative sample for both quantitative and qualitative components. Surveys comprising of mixed approach were administered to obtain both quantitative and qualitative data that were latter assessed to create a comprehensive understanding of the impacts of the solar-powered irrigation systems.

B. Locale of the Study

The study focused on the dynamic socio-economic landscape of Guimba, a municipality in the province of Nueva Ecija, Philippines, which presents an ideal location to gauge the impacts of solar-powered irrigation systems. Situated in the heart of Central Luzon, a region known for its agricultural productivity, Guimba faces several challenges such as irrigation water scarcity as the municipality experiences seasonal droughts, particularly during the dry season, which can significantly impact agricultural production.

It has been further established as an ideal locale for the research with many farmers in Guimba rely on traditional irrigation methods, such as pump irrigation,

that often encounters hurdles related to fuel costs, maintenance, and environmental impact. In addition, the said region is susceptible to climate change-induced extreme weather events, such as droughts and floods, which can then aggravate water scarcity and agricultural losses.

Correlatively, solar-powered irrigation systems present a viable answer to these problems. Even in times of drought, these systems can supply a consistent and sustainable supply of water for irrigation by utilizing solar energy. Moreover, irrigation powered by solar energy can lessen dependency on fossil fuels, lowering greenhouse gas emissions and promoting environmental sustainability.

By conducting a study in Guimba, Nueva Ecija, researchers can gain valuable and relevant insights into the practical impact of solar-powered irrigation systems on agricultural productivity, water resource management, and rural livelihoods.

C. Population and Sampling

The study brought random participants from the roster of farmers in Guimba, Nueva Ecija to the center of the study as respondents of questionnaires established that reflect their awareness and understanding, impacts on their agricultural production, and perception on water management upon venture into solar-powered irrigation systems

Inasmuch as the researcher identified the population to be the farmers recipient of the established solar-powered irrigation systems implemented under the National Irrigation Administration – Upper Pampanga River Integrated Irrigation Systems which were approximately summing up to 313 farmers recognized within the area of Guimba, Nueva Ecija, a subset of this population equivalent to 173, quite above the minimum sample size to get any kind of meaningful result, were studied to represent the targeted population. The study employed a Simple Random Sampling as each farmer in the population has an equal chance of being selected further aligned with the research objectives and feasibility. A proportionate number of farmers were randomly selected to form the sample along with formulating the structure of the survey disseminated through online and written forms to assess the impacts of solar-powered irrigation systems. Then, completed surveys were gathered and the data obtained were analyzed using appropriate statistical techniques.

D. Research Instrument

The researcher established and distributed structured questionnaires, mainly self-administered, comprising a standardized set of questions with predetermined response options and corresponding Filipino language translation administered through Google Forms to gather the suitable and relevant information necessary for the quantitative and qualitative analysis as part of the assessment on the impacts of solar-powered irrigation systems as reflected through the responses of farmers on their knowledge, experiences, and awareness upon implementation and maintenance of the solar-powered irrigation systems.

The organized questionnaire is utilized to obtain information concerning their comprehension, engagement, and understanding: based on their demographic information which includes their age, gender, education level, farming experience, and farm size; adoption of solar irrigation such as the factors influencing the decision to adopt solar irrigation, year of adoption, and initial and ongoing costs of the system; the impact on agricultural practices through changes in crop yield, water usage, and income, perceived benefits and challenges of solar irrigation, and impact on labor requirements and family livelihood; socio-economic impact defined by changes in household income and expenditure, improved quality of life (e.g., health, education), and community development and social impact; environmental impact interpreted by the perceived impact on water quality and soil health, reduced reliance on traditional irrigation methods, and contribution to climate change mitigation; and future look sighted within plans for future expansion or upgrades to the solar irrigation system and perceived barriers to wider adoption of solar irrigation in the community.

To validate the research instrument, a pilot testing was conducted with 10-15 farmers in Guimba, Nueva Ecija, to test the clarity and understandability of questions, assess data collection feasibility, and gather feedback on relevance and appropriateness of the questions. Based on the feedback, the instruments were revised and refined.

E. Data Gathering Procedure

The data gathering for this research study commenced with clearly outlining the study's purpose and research questions to guide instrument development along with the conduct of a comprehensive review of existing research to identify relevant variables and question formats before the formulation of the questionnaire based on research objectives and literature review findings. Thereafter the identification of the population of farmers in Guimba, Nueva Ecija altogether with calculation of required sample size based on desired statistical power and precision that undergone a simple random sampling.

Potential participants were approached through both face-to-face and online interaction equipped with an explanation of the study to obtain informed consent. Through accomplished and submitted online surveys, Google Forms already recorded and tallied the responses of the chosen respondents. Observed findings as being reflected throughout the results were interpreted in relation to the research questions and objectives.

F. Data Analysis

The data obtained and consolidated through the response from the survey questionnaires were statistically analyzed with the application of percentage technique which is utilized for the quantification and calculation of the knowledge gathered in this study predicated on the responses of the determined respondents as it is the most commonly used for the measurement of average percentage corresponding to each detailed answer towards a single question.

The formula to be used was: % = F / N x 100.

where,

F = answer

% = percentage

N = number of respondents

Qualitative data analysis through open-ended questionnaire responses were systematically coded and categorized to identify recurring themes and patterns related to the impacts of solar-powered irrigation systems. Findings from quantitative and qualitative analyses were integrated to provide a comprehensive understanding of the impacts of solar-powered irrigation systems mechanism and processes. These were further interpreted in light of the research questions and existing literature. Results are then presented clearly and concisely using tables, graphs, and charts, along with detailed explanations.

G. Ethical Consideration

Conducting the research in the context of assessing the impacts of solar-powered irrigation systems among farmers in Guimba, Nueva Ecija manifested an ethical challenge of assuring that participants fully understand the study's purpose, risks, and benefits before agreeing to participate alongside with protecting their personal information and maintaining the confidentiality of their responses. This phenomenon was addressed through indicating in the online and written forms prior to putting in their responses that data and information gathered will be treated with utmost confidentiality in accordance with the Data Privacy Act of 2012 (RA 10173) and the online survey shall be used for academic purposes only.

IV. RESULTS AND DISCUSSIONS

Presentation, Analysis, and Interpretation of Data

I. Demographic Information

A. Age Group

Table 1. This table presents to which age group the roster of farmers in Guimba, Nueva Ecija as respondents belong though further submits valuable insights into how different generations perceive and engage with solar-powered irrigation systems, and how its impact varies across different age bracket. It can be gleaned from the data that twenty-seven respondents (15.61%) were from age group 18-25 years old; thirty-eight (21.97%) from age group 26-35 years old; fifty-nine (34.10%) from age group 36-45 years old; thirty-one (17.92%) from age group 46-55 years old; and eighteen (10.40%) were from age group 56 and above years old summing up to a total of 173 farmers throughout different areas of Guimba, Nueva Ecija.

Age Group	No. of Respondents	Percentage
18-25 years old	27	15.61%
26-35 years old	38	21.97%

36-45 years old	59	34.10%
46-55 years old	31	17.92%
56 and above years old	18	10.40%
Total	173	100%

The study funneled on the adoption and use of technology in agriculture, specifically targeting middle-aged farmers aged 35-55 who have significant farming experience and are open to new technologies. Younger farmers aged 25-35 were more tech-savvy and open to innovation. While older farmers also benefitted from solar-powered irrigation, their level of technological literacy and willingness to adopt new technologies varied. Therefore, focusing on these demographics delivered a more accurate assessment of the impact of solar-powered irrigation systems.

The research sought to understand the adoption and adaptation of solar-powered irrigation systems by middle-aged and younger farmers. It measured challenges and opportunities, evaluated the long-term sustainability of these systems, and assessed their economic and social implications. The research contributed a comprehensive understanding of factors influencing the adoption, use, and impact of solar-powered irrigation systems in rural communities.

B. Gender

Table 2. This table shows the proportion of respondent-farmers from different gender group in Guimba,Nueva Ecija. As revealed in the data shown, majority were male with representation of one-hundred eleven (64.16%) respondents; and sixty-two (35.84%) were female.

Gender	No. of Respondents	Percentage
Male	111	64.16%
Female	62	35.84%
Total	173	100%

The study included both male and female farmers, corresponded to the survey instrument being designed to capture gender-specific experiences and challenges. This facilitated a more diverse understanding of the impact of solar-powered irrigation systems on rural communities mainly in Guimba, Nueva Ecija, considering potential gender-specific differences in workload, decision-making, and resource access.

Furthermore, the survey magnified the gender-specific experiences and challenges related to the adoption and use of solar-powered irrigation systems. It incorporated a representation on gender roles and decision-making, access to resources and training, time use and workload, and social and cultural factors. This manifested how women share involvement in decision-making processes, how gender roles influence the distribution of benefits and burdens, and how solar irrigation integrates with women's work-life balance and overall well-being. By analyzing these factors, researchers can develop targeted interventions and policies to promote gender equity and empower women in rural communities as well.

C. Educational Attainment

Table 3. This table manifests the percentage of the respondents with their corresponding educational attainment. As depicted in the table, thirty-one (17.92%) reached elementary level, thirty-seven (21.39%) were elementary graduates, forty-eight (27.75%) attained high school level, twenty-five (14.45%) were high school graduate, nineteen (10.98%) fulfilled college level, while thirteen (7.51%) were college graduates.

Educational Attainment	No. of Respondents	Percentage
Elementary Level	31	17.92%
Elementary Graduate	37	21.39%
High School Level	48	27.75%
High School Graduate	25	14.45%
College Level	19	10.98%
College Graduate	13	7.51%
Total	173	100%

Higher levels of education have significantly modified farmers' understanding, adoption, and use of solar-powered irrigation systems. Higher education was associated with greater technological literacy, decision-making, and innovation. Farmers with higher education have better access to information and training, enabling them to make informed choices and adopt best practices. Higher education has also facilitated better communication with extension

services. The study then integrated interventions to address different groups' needs, maximizing the impact of solar-powered irrigation systems and promoting sustainable agricultural practices.

The research findings indicated a positive correlation between farmers' educational attainment and the adoption of solar-powered irrigation systems in Guimba, Nueva Ecija. Higher education levels were associated with better understanding of solar irrigation technology, improved technical skills, enhanced decision-making abilities, and community leadership. Educated farmers were more likely to adopt innovative agricultural practices and diversify their income sources. However, other factors like access to information, financial resources, and government support also served essential roles. Understanding this relationship can help design targeted interventions to improve rural communities' livelihoods.

D. Years of farming experience

Table 4. This table exhibits the span (in years) of farming experience by farmers in Guimba, Nueva Ecija as being indicated by the respondents. From the data gathered, thirty-two (18.50%) were less than 5 years as farmers in Guimba, Nueva Ecija; thirty-five (20.23%) were in 5-10 years; thirty-seven (21.39%) were in 11-15 years; forty-three (24.86%) were in 16-20 years; and twenty-six (15.02%) were more than 20 years of farming experience in Guimba, Nueva Ecija.

Years of Farming Experience	No. of Respondents	Percentage
Less than 5 years	32	18.50%
5-10 years	35	20.23%
11-15 years	37	21.39%
16-20 years	43	24.86%
20 and above years	26	15.02%
Total	173	100%

The years of farming experience of the respondents yielded valuable and relevant insights into their understanding of agricultural practices, risk tolerance, and willingness to adopt new technologies like solar-powered irrigation systems. For instance, farmers with more years of experience were more cautious in adopting new technologies due to potential risks and uncertainties. However, their experience can also help them identify the potential benefits of solar irrigation and overcome challenges.

Meanwhile, younger farmers were more open to new technologies and willing to experiment with innovative practices. Besides they may have better access to information and training, which can facilitate the adoption of solar irrigation. Through the data based on years of farming experience, the researcher determined specific training needs, extension services, and support mechanisms to promote the adoption and effective use of solar-powered irrigation systems among different groups of farmers.

E. Farmland Size (in hectares)

Table 5. This table views the collective feedback from the respondents when asked about the size of land they used for farming. As presented in the data, twenty-two of them (12.72% of the total respondents) utilizes less than 1 hectare; thirty (17.34%) for 1-2 hectares; fifty-seven (32.95%) for 2-5 hectares; thirty-eight (21.97%) for 5-10 hectares; and twenty-six (15.02%) for 10 and above hectares.

Responses	No. of Respondents	Percentage
Less than 1 hectare	22	12.72%
1-2 hectares	30	17.34%
2-5 hectares	57	32.95%
5-10 hectares	38	21.97%
10 and above hectares	26	15.02%
Total	173	100%

The size of a farmer’s landholding substantially determined the trend for the adoption and impact of solar-powered irrigation systems. Small-scale farmers such as those with less than one hectare to two hectares of farmlands may benefit most from solar-powered irrigation systems as they often face challenges in accessing reliable water sources most especially those situated at the tail-end portion of canals and any available reservoir. Smaller systems may be more affordable and easier to manage for these farmers.

On the other hand, large-scale farmers with five hectares and above landholdings may demand more extensive solar irrigation systems to cover their entire area. Hence, they were most likely capacitated to provide resources and expertise to invest in larger-

scale systems and potentially benefit from economies of scale. Ultimately, the impact of solar irrigation on crop yield and income varied depending on farm size. Smaller farms experienced a more significant increase in productivity due to better water management and augmented irrigational activities.

II. Socio-economic Impact

A. Income and Livelihood:

Table 6. This table reflects the combined responses of farmers when inquired if their total annual income increased since utilizing the solar-powered irrigation system in which twenty-eight of them (16.18%) weighed significantly increased; forty-nine (28.32%) were moderately increased; thirty-seven (21.39%) were slightly increased; forty-three (24.86%) stayed the same and sixteen (9.25%) said decreased.

Responses	No. of Respondents	Percentage
Significantly increased	28	16.18%
Moderately increased	49	28.32%
Slightly increased	37	21.39%
Stayed the same	43	24.86%
Decreased	16	9.25%
Total	173	100%

The significance of the majority of the respondents reporting an increase in their total annual income since their adoption of solar-powered irrigation systems, recognized the reliability and efficiency of water supply provided by the said solar-powered irrigation systems further leading to increased crop yields and higher quality produce. Hence, these can result in higher market prices and greater overall income for farmers.

B. Quality of Life

Table 7. This table depicts the unified thoughts between respondents when queried if the established solar-powered irrigation system improved the farmer's quality of life in any way whereupon twenty-five (14.45%) echoed an absolute response of "Strongly Agree"; seventy-three (42.20%) concurred to "Somewhat Agree"; forty-seven (27.17%) were "Neutral"; twenty-one were "Somewhat Disagree"; while only seven (4.05%) of the total farmers responded "Strongly Disagree"

Responses	No. of Respondents	Percentage
Strongly Agree	25	14.45%
Somewhat Agree	73	42.20%
Neutral	47	27.17%
Somewhat Disagree	21	12.14%
Strongly Disagree	7	4.05%
Total	173	100%

Interpretations from the above-presented collective responses from the chosen respondents expressed that solar-powered irrigation systems have significantly improved the quality of life for farmers in Guimba, Nueva Ecija. This further denoted the enhanced economic security, improved health and well-being, social and community development, and environmental stewardship. Increased income, reduced reliance on traditional methods, and reduced exposure to harmful chemicals implied better financial stability and investment in the future.

C. Community Impact

Table 8. This table submits the shared responses of farmers in Guimba, Nueva Ecija when concurred if the operation of solar-powered irrigation systems has benefited their community in any way alongside which forty-five (26.01%) of them corresponded to "Strongly Agree"; seventy-five (43.35%) accorded to "Somewhat Agree"; thirty-six (20.81%) were "Neutral"; thirteen (7.52%) were "Somewhat Disagree"; while only four (2.31%) of the total respondents conveyed "Strongly Disagree".

Responses	No. of Respondents	Percentage
Strongly Agree	45	26.01%
Somewhat Agree	75	43.35%
Neutral	36	20.81%
Somewhat Disagree	13	7.52%
Strongly Disagree	4	2.31%
Total	173	100%

Corresponding to the gathered responses from the chosen farmers of Guimba, Nueva Ecija, solar-

powered irrigation systems indicated numerous community benefits, including economic development, social development, environmental benefits, and resilience to climate change. Increased agricultural production stimulated local economies, creating jobs and income. Improved market access and reduced transportation costs enhanced economic activity. Solar-powered irrigation also augmented social cohesion, education, healthcare access, and somehow declined migration from rural to urban areas. Understanding these community-level impacts can help policymakers promote the adoption of these systems for sustainable rural development.

III. Environmental Impact

A. Water Usage

Table 9. This table represents the combined feedback from the chosen respondents as to whether the solar-powered irrigation system has helped them use irrigation water more efficiently whereby twenty-eight (16.18%) of them countered to "Strongly Agree", forty-nine (28.32%) were "Somewhat Agree"; sixty-five (37.58%) were "Neutral"; twenty-six (15.03%) were "Somewhat Disagree"; and five (2.89%) declined to further "Strongly Disagree".

Response	No. of Respondents	Percentage
Strongly Agree	28	16.18%
Somewhat Agree	49	28.32%
Neutral	65	37.58%
Somewhat Disagree	26	15.03%
Strongly Disagree	5	2.89%
Total	173	100%

The results expressing a higher number of responses from neutrality to upper affirmative replies than with lower disagreeing remarks conveyed that solar-powered irrigation systems improve water use efficiency through enabling precise irrigation techniques, real-time monitoring and control, reduced water extraction, and environmental benefits. These systems enable farmers to apply water directly to the root zone of plants, reducing water consumption. Solar-powered pumps also reduce water reliance on traditional methods, conserving groundwater levels. This leads to reduced water pollution, soil erosion, biodiversity conservation, and ecosystem health. Understanding these benefits can help promote sustainable agriculture.

B. Water Quality

Table 10. This table reveals the farmers' assessment on the quality of water how it was affected subsequent to consumption with irrigation drawn out from the solar-powered irrigation system. As for the consolidated results, it indicates that eighteen (10.40%) appraised to "Significantly Improved"; seventy-four (42.77%) implied "Partially Improved"; sixty (34.68%) were "Neutral" about it; thirteen (7.51%) gauged to "Partially Worsened"; while eight (4.62%) went to "Significantly Worsened".

Responses	No. of Respondents	Percentage
Significantly Improved	18	10.40%
Partially Improved	74	42.77%
Neutral	60	34.68%
Partially Worsened	13	7.51%
Significantly Worsened	8	4.62%
Total	173	100%

Presented findings further signified that based on the perceptions of the chosen farmers as respondents throughout the research study, solar-powered irrigation systems can potentially improve water quality by reducing pollution and sedimentation. However, excessive pumping of groundwater and poor maintenance can lead to depletion and salinization. Understanding the impact of solar-powered irrigation on water quality requires considering the specific context, local regulations, and farmers' practices.

C. Soil Health

Table 11. This table reflects the unified insights from the farmers regarding the impact of the established solar-powered irrigation system on soil health such that thirty-four (19.65%) designated to "Significantly Improved"; fifty-three (30.64%) estimated "Partially Improved"; sixty-eight (39.31%) settled to "Neutral"; eighteen (10.40%) rated "Partially Worsened"; and none went for "Significantly Worsened".

Responses	No. of Respondents	Percentage
Significantly Improved	34	19.65%

Partially Improved	53	30.64%
Neutral	68	39.31%
Partially Worsened	18	10.40%
Significantly Worsened	0	0.00%
Total	173	100%

Respondent-farmers returning majority of responses from being neutral to significantly improved than with significantly worsened were more inclined that solar-powered irrigation systems strengthen soil health by enhancing nutrient uptake, reducing chemical fertilizer use, and improving soil moisture. However, excessive water application can lead to waterlogging and intensify soil salinity, negatively impacting soil health. Factors such as soil type, irrigation practices, and water quality should be considered to fully understand the impact of solar-powered irrigation on soil health. Despite that, this data can already support to identify best practices for managing soil moisture and fertility.

IV. Technical and Operational Feasibility

A. Irrigation Water Reliability

Table 12. This table outlines the extent of how reliable the solar-powered irrigation system was, in terms of providing water to their crops through which thirty (17.34%) rated very reliable; sixty-three (36.42%) marked reliable; fifty-six (32.37%) expressed moderately reliable, eighteen (10.40%) prompted unreliable; and six (3.47%) said very unreliable.

Responses	No. of Respondents	Percentage
Very reliable	30	17.34%
Reliable	63	36.42%
Moderately reliable	56	32.37%
Unreliable	18	10.40%
Very unreliable	6	3.47%
Total	143	100%

The majority of reliably-like responses indicated a positive perception of the system's consistent water supply, hence a significant number of "unreliable" responses suggested issues with system design, installation, maintenance, or environmental factors. Likewise, water supply is essential for crop growth, affecting yields and quality. Factors affecting consistency include solar panel efficiency, pump capacity, water source availability, and system maintenance. As a conclusion, reliable water supply can lead to increased crop yields and improved quality. However, other factors such as soil fertility, pest and disease management, and market conditions also influence crop outcomes.

B. Ease of Operation

Table 13. This table outlines the extent of how was it easy to operate the solar-powered irrigation system on a daily basis whereupon nineteen (10.98%) rated very easy; sixty-three (36.42%) marked easy; fifty-nine (34.10%) expressed moderately difficult, twenty-five (14.45%) prompted difficulty; and seven (4.05%) said very difficult.

Responses	No. of Respondents	Percentage
Very easy	19	10.98%
Easy	63	36.42%
Moderately difficult	59	34.10%
Difficult	25	14.45%
Very difficult	7	4.05%
Total	173	100%

Correspondingly, the high number of facile responses such as “very easy” and “easy” implied a user-friendly design, while a high number of "difficult" responses submitted complex controls, poor labeling, or inadequate training. Additionally, user-friendly systems that require minimal technical expertise can be easily adopted by farmers with varying levels of education and experience. In addition, adequate training and technical support can also help farmers maximize the benefits of solar-powered irrigation.

C. Maintenance Schedule

Table 14. This table also schemed the extent of how the respondents apprehend the necessity to perform maintenance on the system based on the distinguished assessment of its operation upon which forty (23.12%) rated daily; sixty-seven (38.73%) marked weekly; forty-nine (28.32%) expressed monthly, thirteen (7.51%) prompted yearly; and four (2.31%) said less often.

Responses	No. of	Percentage

	Respondents	
Daily	40	23.12%
Weekly	67	38.73%
Monthly	49	28.32%
Yearly	13	7.51%
Less often	4	2.31%
Total	173	100%

Finally, the amount of high frequency in maintenance indicated complex system design, poor quality components, or harsh operating conditions yet the considerable number of it being less often signified a well-designed and durable system that can operate reliably with minimal intervention. More importantly, regular maintenance can help prevent breakdowns, optimize performance, and prolong the system's lifespan. Otherwise, neglecting maintenance can lead to reduced system efficiency, increased downtime, and higher repair costs.

V. Social Factors

A. Community Involvement

Table 15. This table illustrates the collective feedback from the respondent-farmers towards how involved was their community in the decision-making process for the establishment and operation of the solar-powered irrigation system in their areas by which thirty-nine (22.54%) were very involved; seventy-three (42.2043%) concurred with somewhat involved; forty-two (24.28%) corresponded to minimally involved; while nineteen (10.98%) said their community were not involved at all.

Responses	No. of Respondents	Percentage
Very involved	39	22.54%
Somewhat involved	73	42.20%
Minimally involved	42	24.28%
Not involved at all	19	10.98%
Total	173	100%

A high level of community involvement denoted greater ownership, support, and sustainability of the project. It can guarantee that the system met the specific needs and priorities of the community though those expressed low level to no involvement at all revealed a top-down approach to decision-making, which can lead to dissatisfaction and potential resistance from community members. In essence, community involvement can empower farmers by giving them a voice in decision-making and increasing their capacity to address local challenges. It resonates a sense of ownership and responsibility for the system, leading to better maintenance and long-term sustainability.

B. Social Acceptance

Table 16. This table forwards the consolidated remarks from the respondent-farmers when queried about how well-accepted was the establishment and operation of the solar-powered irrigation system by their neighbors and community members whereby fifty-six (32.37%) corresponded to very well-accepted; eighty-eight (50.87%) to somewhat accepted; twenty (11.56%) to minimally accepted; and nine (5.20%) voiced to not accepted at all.

Responses	No. of Respondents	Percentage
Very well-accepted	56	32.37%
Somewhat accepted	88	50.87%
Minimally accepted	20	11.56%
Not accepted at all	9	5.20%
Total	173	100%

High levels of social acceptance conveyed smooth implementation and operation of the system. It also signified increased community support and cooperation. However, the small proportion belonging to low levels of social acceptance represented various factors, such as concerns about noise pollution, visual impact, or perceived negative effects on the environment. Ultimately, addressing community concerns proactively can help mitigate potential conflicts and ensure the long-term sustainability of the project. Effective communication, transparency, and community engagement can help build trust and alleviate concerns.

C. Knowledge and Awareness

Table 17. This table presents the amplitude of responses from farmers when gauging how much they knew about solar energy and its applications in agriculture. Based from the tabulation, it showed that

twenty-three (13.29%) of them knew about it to a great extent; seventy-four (42.77%) somewhat recognized its existence; fifty-nine (34.10%) have very little knowledge; while seventeen (9.84%) knew nothing at all.

Responses	No. of Respondents	Percentage
To a Great Extent	23	13.29%
Somewhat	74	42.77%
Very Little	59	34.10%
Nothing at all	17	9.84%
Total	173	100%

A high level of awareness manifested the adoption of solar-powered irrigation systems by reducing uncertainty and increasing confidence in the technology. Meanwhile, little to no knowledge and awareness at all exhibited hindrance of the adoption and require targeted education and outreach efforts to inform farmers about the benefits and potential of solar energy. Accordingly, access to reliable information sources can help farmers make informed decisions about technology adoption notwithstanding the fact that misinformation or inaccurate information can lead to misunderstandings and negative perceptions.

VI. Institutional Factors

A. Government Support

Table 17. This table furnishes results based from the responses of the farmers if the government had provided support or subsidies for the establishment and installation of the solar-powered irrigation systems within their areas toward which a decisive majority of one hundred fifty-seven (90.75%) respondents took an absolute acknowledgement responding “Yes”, though there were still sixteen (9.25%) who implied otherwise.

Response	No. of Respondents	Percentage
Yes	157	90.75%
No	16	9.25%
Total	173	100%

Significant government support meant for the acceleration of the adoption of solar-powered irrigation systems by reducing upfront costs and incentivizing farmers though the other way blocked adoption, particularly for smallholder farmers who may lack the financial resources to invest in these technologies. Definitely government support prompted the adoption of solar-powered irrigation systems by reducing financial barriers and increasing awareness yet insufficiency or poorly targeted priorities caused a limited impact on adoption rates.

B. Extension Services

Based on the shared answers from the respondents whether they had received any training or technical assistance from agricultural extension services of any government institution or irrigation agencies regarding the operation and maintenance of the solar-powered irrigation systems, the numbers reflected on the affirmative side still reached a greater portion with ninety-eight (56.65%) agreeing to the statement, while seventy-five (43.35%) stating otherwise.

Response	No. of Respondents	Percentage
Yes	98	56.65%
No	75	43.35%
Total	173	100%

High levels of training and technical assistance echoed enhancement of farmers' knowledge and skills, leading to more efficient operation and maintenance of solar-powered irrigation systems. Furthermore, accessible and timely extension services delivered the farmers with the support they need to address technical issues and optimize the performance of their systems.

CONCLUSION

The findings of this research indicated promising results in boosting agricultural productivity and sustainability through harnessing solar energy in which farmers of Guimba, Nueva Ecija have collectively acquired greater control over water resources, leading to increased crop yields, improved crop quality, and reduced reliance on traditional use of diesel-powered water pumps. Solar-powered irrigation systems resonated an innovative solution to

address the frequent and fluctuating challenges faced by farmers in certain areas that were not reached by gravitational irrigation network most especially those in far-flung areas. By promoting sustainable agricultural practices and improving the livelihoods of rural communities, this technology has the potential to contribute to the overall development and resilience of the agricultural sector.

Furthermore, the study also concluded that the implementation of solar-powered irrigation systems in Guimba, Nueva Ecija has helped the farmers utilize irrigation water more efficiently based on their assessment. In addition, it has also improved water quality by reducing pollution and sedimentation. Farmers who responded were more likely to believe that solar-powered irrigation systems improve soil moisture, increase nutrient uptake, and decrease the need of chemical fertilizers.

As for technical and operational feasibility, the majority of respondents positively perceived the system's consistent water supply, while "unreliable" responses suggested issues with design, installation, maintenance, or environmental factors. Meanwhile, most of them indicated a user-friendly design, while a significant number of responses suggested complex controls, poor labeling, or inadequate training, suggesting that solar-powered irrigation can be easily adopted in terms of the ease for operation.

Finally, solar-powered irrigation systems in Guimba, Nueva Ecija obtained distinction due to reduced operational costs, increased crop yields, and improved water security. However, challenges like high initial investment costs and limited technical expertise persisted. Targeted policies, financial incentives, and capacity-building programs can facilitate widespread adoption. Future research should explore long-term impacts on agricultural productivity, environmental sustainability, and rural livelihoods whether in a larger scale or different perspectives.

RECOMMENDATION

Based on the conducted assessment on the impacts of solar-powered irrigation systems among farmers in Guimba, Nueva Ecija, the following recommendations are put forth to enhance these community projects for further adoption as part of community extension services, benefiting more people in the future:

- Implement targeted subsidies or low-interest loans to reduce farmers' initial investment costs and explore innovative financing mechanisms like lease-to-own programs for solar irrigation system accessibility.
- Offer farmers with comprehensive training on solar irrigation systems; establish technical support services; and promote the use of user-friendly, affordable technologies.
- Invest in reliable power distribution networks for solar irrigation systems and enhance rural road networks for the transportation of solar equipment and agricultural products.
- Upgrade research and development that shall focus on improving solar irrigation systems' performance and cost-effectiveness, while developing innovative technologies tailored to small-scale farmers' needs.
- Reinforce farmer organizations by supporting their formation and capacity building, encouraging them to invest in solar irrigation systems, and sharing the benefits among their members.
- Augment solar irrigation initiatives by fostering inter-agency collaboration among government agencies, NGOs, and private sector organizations, and establishing a task force for program monitoring.
- Establish a resilient regulatory framework that encourages the use of renewable energy technologies in agriculture.

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This research is dedicated to the hardworking farmers whose unwavering dedication as front liners for food production inspires us all, with the hope that the findings will contribute to the enhancement and augmentation of more solar-powered irrigations systems for a much sustainable and prosperous world.

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