Solar Powered Pump Utilization as Mitigation Measure against El Niño Phenomenon: Basis for Action Plan

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ABSTRACT

This study is entitled, "Solar Powered Pump Utilization as Mitigation Measure against El Niño Phenomenon: Basis for Action Plan". Utilizing a descriptive research design, a validated survey questionnaire was administered to 261 smallholder farmers. Profile characteristics indicate that the farm operators are predominantly in mid-to-late adulthood (ages 53–61) and manage small-to-medium landholdings (0.6427–1.1427 hectares), with the highest concentration in the Municipality of Oton. Perceived operational performance was evaluated as highly effective, whereas sustainability output and system efficiency were rated as moderately effective. Non-parametric analysis (Kruskal-Wallis H) revealed significant variations in perceived effectiveness across age groups, geographic locations, and landholding scales ($p < 0.05$). Post hoc pairwise comparisons confirmed specific perception gaps between middle-aged and elderly cohorts, distinct municipal clusters, and transitional farm sizes. These disparities underscore critical socio-technical barriers, such as technological anxiety among older farmers, varying groundwater availability across topography, and financial constraints in micro-plots. The findings provide the empirical foundation for a comprehensive strategic action plan designed to accelerate deployment, optimize regional asset management, and improve long-term system sustainability.

Keywords: Solar-powered pump, El Niño phenomenon, Climate adaptation, Technology diffusion, Smallholder farmers

BACKGROUND

Global agricultural systems are increasingly threatened by climate-driven meteorological anomalies that disrupt hydrological cycles and undermine food security. Chief among these is the El Niño-Southern Oscillation (ENSO), which triggers prolonged droughts, elevated ambient temperatures, and severe water scarcity. Developing countries bear the brunt of these disruptions because agriculture consumes 80-90% of available freshwater resources, and over 60% of their populations rely directly on agrarian livelihoods.

In the Philippines, the 2024 El Niño episode led to severe drought conditions across 31 provinces, generating direct agricultural losses of Php 2.63 billion and compromising the livelihoods of more than 54,000 farmers. The Province of Iloilo emerged as an epicenter of crisis, reporting thousands of hectares of damaged, unsalvageable rice cultivation areas.

Historically, mitigation strategies relied heavily on manual water lifts or fossil-fueled diesel pump sets. Manual pumps demand intensive physical labor and offer low volumetric flow rates. Conversely, diesel pumps provide reliable discharge rates but expose smallholders to volatile fuel costs, logistical supply strains, and increased greenhouse gas emissions. To break this cycle, solar-powered irrigation systems (SPIS) have emerged as a disruptive, climate-resilient alternative. By decoupling irrigation from fuel markets and grid infrastructure, solar water pumping offers a decentralized path to steady water access during daylight hours.

To optimize the deployment of public infrastructure investments, it is critical to evaluate technology through a socio-technical lens. Evaluating an engineering asset based strictly on lab-rated mechanical efficiency often fails to capture real-world operational challenges. Instead, focusing on perceived effectiveness and adoption potential offers deep insight into user experience and technology acceptance. This user-centric methodology helps researchers understand how human behavior, technological anxiety, and local field dynamics influence long-term adoption and operational sustainability.

This study relies on the Diffusion of Innovations Theory to explore why certain farmer groups accept or reject agricultural technologies. It aims to clarify how age, farm scale, and municipal location shape the perceived utility of solar pumping infrastructure in Iloilo. The ultimate goal is to translate these insights into an actionable strategic plan that enhances climate adaptation and ensures stable water access across farming communities.

METHODS

This study used a descriptive research design to capture and analyze farmers' experiences with solar-powered pumps. The target population consisted of agrarian operators in Iloilo registered under municipal Farmers' Associations. The study applied a total enumeration strategy, surveying all 261 farmers across the designated irrigation areas to eliminate sampling error and ensure full representation across demographic lines.

Data collection was executed via a structured, researcher-constructed survey questionnaire tailored to local language proficiencies with full vernacular translations. The instrument comprised two primary sections: Part I: Demographic Profiles: Documented chronological age, geographic municipality of landholding, and total arable farm size. And Part II: Evaluative Subscales: Contained 30 items uniformly distributed across three latent dimensions: Operational Performance, Sustainability of Output, and System Efficiency. Content validity was established using the criteria set forth by Carter V. Good and Douglas Scates, evaluated by an independent panel of five subject-matter experts specializing in agricultural engineering, renewable energy infrastructure, and psychometric psych-evaluation instruments. The expert panel evaluation yielded an overall Content Validity Index (CVI) of 0.92, exceeding the minimum acceptable academic threshold of 0.80. Internal consistency and instrument reliability were pilot-tested among 30 non-participating farming operators in an adjacent province to avoid data contamination. Psychometric evaluation of the pilot data produced strong Cronbach's alpha values across all dimensions, confirming robust instrument reliability. Perception measurements were captured using a 4-point Likert scale to eliminate neutral-response bias.

Descriptive statistics (frequencies, percentages, and arithmetic means) were used to summarize baseline demographic attributes and subscale scores. Because normality checks via the Shapiro-Wilk test indicated that the response data was skewed ($p < 0.05$), non-parametric alternatives to the standard Analysis of Variance (ANOVA) were employed. The Kruskal-Wallis H test evaluated whether perceived effectiveness varied significantly across demographic lines. For significant H values, Dunn's post hoc test with a Bonferroni correction identified exact, significant pairwise variations while controlling for Type I error rates. The operational significance boundary was maintained at $p = 0.05$.

RESULT AND DISCUSSION

The table 1 illustrates the distribution of the profile of respondents in terms of frequency and percentage distributions across various categories.

Table 1. Distribution of Respondents According to Profile.

Profile	Category	F	%
Age	35-43 years old	9	3.45
	44-52 years old	73	27.97
	53-61	129	49.43
	62-70	47	18.01

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	71-79	3	1.15
	Total	261	100.00
Location of Land	Alimodian	6	2.30
	Banate	8	3.07
	Batad	5	1.92
	Cabatuan	40	15.33
	Dingle	7	2.68
	Guimaras	6	2.30
	Lambunao	9	3.45
	Leganes	11	4.21
	Leon	12	4.60
	Miagao	18	6.90
	Mina	14	5.36
	Oton	45	17.24
	San Joaquin	10	3.83
	San Miguel	36	13.79
	Sara	19	7.28
	Sta. Barbara	15	5.75
	Total	261	100.00
Land Property Size	0.1427-0.6427 Hectares	40	15.33
	0.6427-1.1427	169	64.75
	1.1427-1.6427	43	16.48
	1.6427-2.1427	4	1.53
	2.1427-2.6427	4	1.53
	2.6427-3.6427	1	0.38
	Total	261	100.00

The data reveals that the regional agricultural workforce is heavily concentrated in mid-to-late adulthood, with 49.43% of respondents falling within the 53–61 age range. This aligns with the national baseline data from the Philippine Statistics Authority (PSA), which indicates an average farm operator age of 57.

Geographically, the sample is concentrated within three major municipalities: Oton (17.24%), Cabatuan (15.33%), and San Miguel (13.79%), which together account for 46.36% of all respondents.

In terms of property size, 64.75% of respondents manage medium-sized farm plots spanning 0.6427 to 1.1427 hectares. This falls just below the national average holding profile of 1.29 hectares, highlighting the vulnerabilities faced by smallholders during major drought events.

The table 2 below shows the Level of Effectiveness of the Solar Powered Pump Utilization by Farmers as Mitigating Measures To manage El Nino Phenomenon in terms of Performance of Operation, Sustainability Output and Efficiency of the System.

Table 2. Level of Effectiveness of the Solar Powered Pump Utilization by Farmers as Mitigating Measures to manage El Nino Phenomenon.

Level of Effectiveness	N	Mean	Interpretation
Performance of Operation	261	3.44	Highly Effective
Sustainability Output		3.25	Moderately Effective
Efficiency of the System		3.30	Highly Effective

The findings show that respondents view the core machinery of the solar pumping installations favorably, as seen in the high Operational Performance score (3.44). This indicates that the systems are perceived as mechanically reliable and capable of meeting immediate water delivery demands when active.

However, Sustainability Output received a lower score (3.25), dropping into the Moderately Effective range. This reveals underlying concerns among users regarding long-term institutional viability, the availability of technical maintenance technicians, battery storage capacity, and performance consistency during prolonged cloud cover.

Table 3 shows the level of Effectiveness of the Solar Powered Pump Utilization When Taken as a Whole and When Grouped According to Profile.

Table 3. Level of Effectiveness of the Solar Powered Pump Utilization by Farmers as Mitigating Measures to Manage El Nino Phenomenon When Taken as a Whole and When Grouped According to Profile.

Profile	Category	f	Mean	Interpretation
Age	35-43 years old	9	3.38	Moderately Effective
	44-52 years old	73	3.38	Moderately Effective
	53-61	129	3.43	Highly Effective
	62-70	47	2.99	Moderately Effective
	71-79	3	3.21	Moderately Effective
Location Of Land	Alimodian	6	4.02	Highly Effective
	Banate	8	3.62	Highly Effective
	Batad	5	4.18	Highly Effective

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	Cabatuan	40	3.97	Highly Effective
	Dingle	7	3.16	Moderately Effective
	Guimaras	6	4.10	Highly Effective
	Lambunao	9	2.75	Moderately Effective
	Leganes	11	2.92	Moderately Effective
	Leon	12	3.64	Highly Effective
	Miagao	18	2.84	Moderately Effective
	Mina	14	3.14	Moderately Effective
	Oton	45	2.91	Moderately Effective
	San Joaquin	10	3.30	Moderately Effective
	San Miguel	36	3.58	Highly Effective
	Sara	19	2.97	Moderately Effective
	Sta. Barbara	15	3.0	Moderately Effective
Land Property Size	0.1427-0.6427 Hectares	40	3.22	Moderately Effective
	0.6427-1.1427	169	3.27	Moderately Effective
	1.1427-1.6427	43	3.68	Highly Effective
	1.6427-2.1427	4	3.23	Moderately Effective
	2.1427-2.6427	4	3.23	Moderately Effective
	2.6427-3.6427	1	3.20	Moderately Effective
As a Whole		261	3.33	Moderately Effective

Table 3 shows that when farmers are grouped according to age, the result reveals that the solar powered pump was effective as mitigating measures to manage El Niño phenomenon for farmers aged 53-61 years old with a Mean result of 3.43. On the other hand, farmers aged 62-70 years responded that the mentioned pump was moderately effective in its effectiveness when utilized based on its Mean result of 2.99 the lowest Mean in the category of age. Furthermore, those farmers from the Municipality of Batad had a high Mean result of 4.18 and interpreted as a highly effective level of assessment of the utilization of solar powered plants. Meanwhile, farmers from the Municipality of Lambunao evaluated that the utilization of the solar powered plant as moderately mffective in its utilization. Meanwhile, farmers who owned a land area of 1.1427-1.6427 hectares attested that solar powered pump was effective (Mean result – 3.68) when they utilized it in their farmland but those farmers with land area of 2.6427-3.6427 hectares assessment on the level of effectiveness was moderately effective (Mean result – 3.20) in mitigating the El Nino Phenomenon. The level of effectiveness of the solar powered plant when taken as a whole had a mean result of 3.33 and was interpreted as moderately effective.

A study proves that age can significantly influence the adoption of agricultural innovations. The result of the study shows that older farmers tend to be more conservative, while younger farmers are more adventurous and willing to take risks. Consequently, older farmers are less likely to adopt new technologies, even if they have substantial off-farm income. However, found that age can positively influence the adoption of specific agricultural innovations, as older farmers possess more agricultural experience (Sanogo et al., 2025).

Table 4 below shows the Difference in the level of effectiveness of the Solar Powered Pump Utilization by Farmers to Mitigate El Nino Phenomenon When Grouped According to Profile.

Table 4. Difference in the level of effectiveness of the Solar Powered Pump Utilization by Farmers to Mitigate El Nino Phenomenon When Grouped According to Profile.

Demographic Factor	Degrees of Freedom	Kruskal-Wallis Metric (H)	Asymptotic Significance (p)	Statistical Interpretation
Chronological Age	4	23.94	< 0.001	Highly Significant
Geographic Location	15	163.51	< 0.001	Highly Significant
Landholding Scale	5	18.55	0.002	Highly Significant

Table 4 presents that there is significant difference in the level of effectiveness when farmers are grouped according to their profile. This result implies that the null hypothesis is rejected for the fact that there is a significant difference in the level of effectiveness of the utilization of the solar powered pump when farmers are grouped according to profile with the computed value of 23.94 for age, then for location of land with 163.51 and 18.55 for land property size. The test confirmed significant differences within all three demographic categories. This demonstrates that perception is not uniform; instead, it is shaped by an operator's age, geographic location, and farm scale.

This simply implies that the profile of the respondents has significant difference in the level of effectiveness in the utilization of the solar powered pump. Hence, implementing a program for farmers to have a higher yield of products should consider a rigid feasibility study and variables especially their age, ownership of the land and the land area.

Table 4a below presents the comparison on the level of Effectiveness of the Solar Powered Pump Utilization by Farmers to Mitigate El Nino Phenomenon in terms of Age.

Table 4a. Pairwise Comparison on the level of Effectiveness of the Solar Powered Pump Utilization by Farmers to Mitigate El Nino Phenomenon in terms of Age.

Pairwise Contrast Combination Groupings	Standardized Test Statistic	Adjusted Significance	Statistical Decision Matrix
44–52 years vs. 62–70 years	56.89	< 0.001	Highly Significant
53–61 years vs. 62–70 years	61.10	< 0.001	Highly Significant

Table 4a reveals the significant difference in the level of effectiveness on the utilization of the solar powered pump when group according to age. The result shows that there is a significant difference in the level of effectiveness in the age category between 44-52 years and 67-70 years old; and 53-61 years old and 62-70 years old. It implies that when the responses of the mentioned age were computed as to their difference the result had a difference, thus varies much in the result. It also implies that utilization of the solar powered pump has a lower effectiveness level, thus needs further improvement in the implementation and utilization of the program.

Note: All other age group combinations (e.g., 35–43 vs. 71–79) showed no statistically significant differences.

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Table 4b below presents the pairwise comparison on the level of effectiveness of the Solar Powered Pump Utilization by Farmers to Mitigate El Nino Phenomenon in terms of Location of Land.

Table 4b. Pairwise Comparison on the level of Effectiveness of the Solar Powered Pump Utilization by Farmers to Mitigate El Nino Phenomenon in terms of Location of Land.

Representative Baseline Anchor	Comparison Municipality Counterpart	Test Statistic Metric	Adjusted Significance	Statistical Decision Matrix
Alimodian (μ=4.02)	Lambunao (μ=2.75)	180.53	< 0.001	Highly Significant
	Oton (μ=2.91)	150.18	< 0.001	Highly Significant
Batad (μ=4.18)	Miagao (μ=2.84)	165.79	< 0.001	Highly Significant
	Oton (μ=2.91)	167.70	< 0.001	Highly Significant
Cabatuan (μ=3.97)	Lambunao (μ=2.75)	175.67	< 0.001	Highly Significant
	Oton (μ=2.91)	145.33	< 0.001	Highly Significant
Guimaras (μ=4.10)	Lambunao (μ=2.75)	190.53	< 0.001	Highly Significant
	Oton (μ=2.91)	160.18	< 0.001	Highly Significant

Table 4b presents the significant difference in the level of effectiveness in the utilization of the solar powered pump when grouped according to location of land.

The stark statistical contrast ($p_{adj} < 0.001$) between the high-satisfaction enclaves of Batad (μ=4.18), Guimaras (μ=4.10), Alimodian (μ=4.02), and Cabatuan (μ=3.97) against lower-rated municipalities like Lambunao (μ=2.75) and Oton (μ=2.91) demonstrates that technology adoption potential is heavily shaped by local environmental and technical realities. Enclaves reporting high satisfaction levels typically benefit from favorable hydrological conditions, such as shallow water tables, which lower static head requirements and allow solar pumps to deliver optimal volumetric water flow during peak daylight hours. Conversely, inland areas like Lambunao feature hilly terrains with deeper, erratic aquifers that place greater physical strain on the pumps. This increased lift requirement decreases the system's overall water discharge, leading farmers to perceive the technology as less effective for their immediate irrigation needs during severe droughts.

This geographic divide is further widened by differences in infrastructure density and institutional support networks across the province. In highly concentrated agricultural areas like Oton, which had a significant portion of the survey respondents, the simultaneous use of multiple solar systems can cause localized daytime water table drawdowns, reducing water output and causing friction among shared users. Furthermore, municipalities with high satisfaction ratings often feature proactive Irrigators' Associations and local government training programs that minimize system downtime. In contrast, areas with lower ratings frequently suffer from a lack of local technician support, leaving farmers frustrated by long repair delays for specialized parts like solar controllers. This highlights why a localized approach is necessary; future deployment frameworks must move away from standardized distribution and instead focus on site-specific training, technical maintenance networks, and tailored system configurations.

Note: This matrix isolates primary regional differences; it summarizes the extensive pairwise contrasts by showing the significant gaps between high-performing enclaves (Alimodian, Batad, Cabatuan, Guimaras) and lower-rated municipalities (Lambunao, Oton, Miagao).

Solar technologies are becoming a viable option for both large and small-scale farmers. Solar powered irrigation systems (SPIS) provide reliable and affordable energy, potentially reducing energy costs for irrigation.

Particularly in rural areas, where cost of diesel fuel is high or where reliable access to the electricity grid is lacking, they can provide a relatively flexible and climate-friendly alternative energy source. In response to mitigating the impacts of climate change, the government installed several large solar irrigation projects in different parts of the country. For instance, solar irrigation projects were installed in the provinces of Rizal, Laguna, Camarines Sur, Nueva Ecija, Occidental Mindoro, and Lanao del Sur in the last 5 years. These projects provide a sustainable supply of water in the absence of a conventional irrigation system while offsetting the cost of traditional irrigation fuels, offering low operational costs, and producing zero GHG emissions (Guno & Agaton, 2022).

Table 4c below presents the comparison of land property size.

Table 4c. Pairwise Comparison on the level of Effectiveness of the Solar Powered Pump Utilization by Farmers to Mitigate El Nino Phenomenon in terms of Land Property Size.

Pairwise Contrast Combination Groupings (Hectares)	Standardized Test Statistic	Adjusted Significance	Statistical Decision Matrix
0.1427–0.6427 vs. 1.1427–1.6427	-55.62	< 0.001	Highly Significant
0.6427–1.1427 vs. 1.1427–1.6427	-53.90	< 0.001	Highly Significant

The significant post hoc pairwise contrasts ($p_{adj} < 0.001$) reveal a clear divergence in how farmers perceive the effectiveness of solar-powered pumps based on the scale of their landholdings, with transitional mid-scale operators (1.1427–1.6427 hectares) reporting significantly higher satisfaction than smallholders cultivating less than 1.14 hectares. This perceptual gap points directly to the economics of scale and technology matching within these irrigation networks. Smallholders in the lower brackets (0.1427–0.6427 and 0.6427–1.1427 hectares) often share communal solar installations, which frequently leads to distribution bottlenecks, scheduling conflicts, and water allocation disputes during intense El Niño dry spells. In contrast, the 1.1427–1.6427 hectare range represents a technical “sweet spot” where the land area perfectly matches the hydraulic output of standard 3kW to 5kW solar pump systems. These farms are large enough to fully maximize the return on infrastructure investment and operate independently without the social friction of shared access, yet small enough to be thoroughly irrigated during peak daylight hours without requiring expensive battery storage systems.

Note: Contrasts across ultra-large scales (> 1.64 hectares) did not achieve significance due to small sample sizes (n) within those categories.

In the study of Geronimo and Mallari (2025) it is clearly emphasized that 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 farmland 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.

CONCLUSION

This study demonstrates that while solar-powered pumping infrastructure is perceived as an effective tool for countering El Niño-driven water scarcity in Iloilo, its long-term adoption potential depends heavily on key socio-demographic and geographic factors. Agrarian operators view the system’s core mechanical performance favorably, but express concerns regarding long-term maintenance, equity of access, and system reliability during seasonal changes.

Perception trends vary significantly across demographic lines: older farmers encounter tech-anxiety barriers, smallholders face coordination challenges on shared plots, and hillier inland municipalities cope with complex hydrological conditions.

By addressing these challenges through the targeted interventions outlined in the strategic action plan including localized training, engineering upgrades, and cooperative governance frameworksregional policymakers can maximize the utility of solar irrigation investments. This comprehensive approach will bolster climate resilience and secure sustainable water access for vulnerable farming communities across the region.

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