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Assessing the post-construction support for solar water-pumping systems in rural communities in Indonesia

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Abstract

Community-scale solar water-pumping systems (SWPSs) have become ideal alternatives for remote villages that lack electricity and water access. In Indonesia, SWPSs have been installed in many villages, but they often malfunction. Although technical studies are available, evidence showing the effect of post-construction support on the interplay in SWPS projects is scarce. Therefore, this study examined the post-construction support from the perspectives of the communities and local actors in four SWPS projects in rural Indonesia using a questionnaire survey. Three types of support were considered in the research framework and selected as dependent variables for regression analysis: capacity building, financial assistance, and technical assistance. Data were collected from 275 beneficiaries and 11 local actors, including local governments and implementing organizations, and statistical analysis was conducted. The results showed that, on average, the communities perceived that the community-based organization (CBO)–a local team that manages SWPS projects–was incapable of solving problems independently. Moreover, the existing support was inadequate and did not meet the requirements of the communities. This study found three determinants of the need for support: technical skills, funds for technical assistance, and financial management (eigenvalues of 2.89, 1.51, and 1.23, respectively). Logistic regression analysis revealed that technical skills were particularly crucial because this factor significantly determined the need for all types of support ($p < 0.05$ and $p < 0.01$). However, relying on the support of local actors is difficult, because of their limited resource availability. These findings highlight the significance and role of the support aspect in achieving the sustainability of renewable energy projects in rural areas. Although increased effort to improve the capabilities of the CBOs is necessary, future projects must also consider the trade-off between renewable energy technology and the consequent need for support. Accordingly, designing projects that promote support from all stakeholders is imperative.

Keywords Solar water-pumping systems · Renewable energy · Community project · Post-construction support · Rural community · Local stakeholders

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1 Introduction

In developing countries with limited national grid, solar water-pumping systems (SWPSs) are an ideal solution to meet the demands of water supply and micro-irrigation in villages. This technology is classified as solar photovoltaics (PV) for productive use, and provides the direct benefit of a water pumping and supply system that has minimal environmental impacts and is more affordable than diesel-powered pumps in the long run (Bannister, 2000), particularly considering the high diesel prices in rural areas. The system uses renewable energy (RE) from sunlight to generate electricity, which then operates a pump to lift water. Moreover, an SWPS is considered technologically advanced and reliable, has low operational costs, and is expected to last for 20 years (UNESCAP, 1991).

The sustainability of RE technology and the societal context depend not only on technical functionality, but also on social and institutional factors (Fudge et al., 2016). After construction is completed, the implementing organizations generally transfer responsibility for operation and maintenance to a community-based organization (CBO), which is a group of local communities that manages the system. However, mismatches often occur between the prescribed and actual capacities of the CBO, thereby affecting the sustainability of the project (Hjalmarsdottir, 2012). Although the community management approach provides increased control and opportunity for strategic decision-making to communities, regular support is crucial for a technically complex system that cannot be easily operated and maintained (IRC, 2001). Moreover, Rahmani et al. (2020) concluded that extensive and continuous post-construction support from an institution is a factor that contributes to the success of sustainable community RE projects. Without a supportive environment, these projects as innovations cannot be sustained and developed (Dobravec et al., 2021). Support for pump technology have only focused on the assessment of hand pumps and wells; therefore, a gap exists in the literature on mechanized pipe water systems, which are more complex and require additional assistance (Miller et al., 2019). Thus, investigating the support for RE projects, especially solar-powered pumps, has become imperative with increased installation of RE systems, particularly in developing countries, to expand access to basic human needs using low-carbon technology.

Indonesia is a developing country that has actively implemented the SWPS. Approximately 189 SWPS projects were reported in Indonesia between 2005 and 2021 (Lorentz, 2021). Many studies on the SWPSs in the country have explored technical aspects, such as design and construction reports (Primawan & Iswanjono, 2019), and the analysis of technology performance corresponds to economic analysis (Usman et al., 2018). Regarding the social aspects of SWPSs, scholars have investigated the process of transferring knowledge (Salis et al., 2018) and the participation of different stakeholders (Wahyuni et al., 2015). Recently, research has been conducted on the socio-economic impact of the SWPSs in Indonesia (Rahmani et al., 2021) and its local governance (Rahmani et al., 2023). Globally, the literature on community-scale RE projects has focused on sustainability assessment, for example, from the techno-social and socioeconomic perspectives (Hong & Abe, 2012), and on the evaluation of project performance (López-González et al., 2019). In the social aspect, various topics have been explored, such as community engagement (Joshi et al., 2019), social mobilization in the context of energy transition (Marquardt & Delina, 2019), management failure (Ikejemba et al., 2017), socioeconomic impacts, and impacts related to the millennium development goals (Terrapon-Pfaff et al., 2014). Nevertheless, scientific research on the support aspect is scarce. This study aims to improve the understanding and provide empirical evidence of the support aspect for an SWPS by proposing a novel analytical framework from the perspectives of communities and local actors (local governments and implementing organizations).

This study emphasized that support from external communities is essential for the sustainability of SWPS projects. The following research question was addressed: What are the determinants of the need for support in SWPS projects? The study was conducted in two steps. First, an analytical framework and hypotheses were formulated, and these hypotheses were tested on four SWPS projects in the rural Gunungkidul District, Indonesia. Second, data were collected through a questionnaire survey administered to communities and local actors. The communities were enquired about their evaluation of SWPS project performance, current existing support, and the need for support, whereas local actors were asked about their interest in SWPS technology, availability of resources, and capability to provide support.

The following section, Sect. 2, discusses the analytical approaches employed for examining the support from both communities and local actors. Sections 3 and 4 describe the study area and the methods used, respectively. Section 5 presents the results of the study and Sect. 6 elaborates on the findings considering the relevant literature. Finally, Sect. 7 concludes the paper.

2 Analytical approaches

Previous research on a community-scale SWPS (Rahmani et al., 2023) interviewed the CBO or project management team about crucial factors that influence the sustainability of the SWPS. The three crucial factors were insufficient skills, lack of a reserve budget, and the repair of electrical damage. Based on these results, this study interpreted these three factors as three types of necessary support: (1) capacity building, (2) financial assistance, and (3) technical assistance. These three types of support were selected as dependent variables in the regression analysis used to predict the determinants of the need for support.

This study investigated the support dimension for an SWPS according to two scopes of assessment: the perspectives of the communities and local actors. This section elaborates on the applied theoretical approaches for each scope.

2.1 Framework for the perspective of communities

The sustainable performance of an SWPS, particularly a community-managed project, involves multiple indicators in internal communities, including skill, financial, and technical factors (Short & Thompson, 2003). The skill indicator relates to the capability and knowledge of the CBO managing the system, whereas the financial indicator concerns the user's commitment to pay a service fee, affordability, and incentives for the team. The technical indicator is related to the technological aspects of an SWPS, including ease of use, ease of maintenance, and technology durability. The SWPS operates only during the day under sunlight exposure, and the daily output varies depending on the solar radiation conditions (UNESCAP, 1991), which affect water sufficiency for household consumption. The community-based evaluation in this study also included their perspectives on assistance for the SWPS, both the existing support and the need for support in terms of capacity building, technical assistance, and financial assistance.

2.2 Framework for the perspective of local actors

Generally, a sense of shared responsibility exists among the stakeholders involved in supporting and improving the local system (Chaudhuri et al., 2020). Two types of support models are available for a community-managed rural water supply system: a demand-driven approach, where the responsibility to seek services is on the communities themselves, and a supply-driven approach, where a provision of technical assistance, repairs, and other services is included (The World Bank, 2009). Considering an SWPS in a local context, this study assessed the local government's capacity to provide support for an SWPS. Local government refers to the government structure below the national government; that is, provinces, districts (*kabupaten*), subdistricts (*kecamatan*), and villages (*desa*) (Usman, 2001). Implementing organizations, such as international donors, national agencies, universities, and non-profit organizations (NPOs), were also included because they played a crucial role during project development. Herein, the local governments and implementing organizations were defined as "local actors."

The degree to which local actors can provide support is related to the interest in RE technology and the availability of resources (Mey et al., 2016). High interest can drive local actors to engage in activities related to providing support. Appropriate oversight and supportive action from local actors includes efforts to allocate resources within the institution (Derks & Romijn, 2019). An agency with limited resources may have a lower capacity to provide support. The assessment of local actors also included their perspectives on their ability to provide support for capacity building, financial assistance, and technical assistance.

The proposed framework is shown in Fig. 1. Based on the aforementioned literature, the research variables were formulated, as shown in Tables 1 and 2 in the Methodology section.

3 Study area

The hypothesis was tested at four project locations in the Gunungkidul District, Yogyakarta Province, Indonesia. Gunungkidul is a karst, where the landscape typically comprises carbonate rocks, and the aquifers form a distinct underground water stream (Hartmann et al., 2014). Owing to the hilly topography, population settlements are mostly concentrated in a

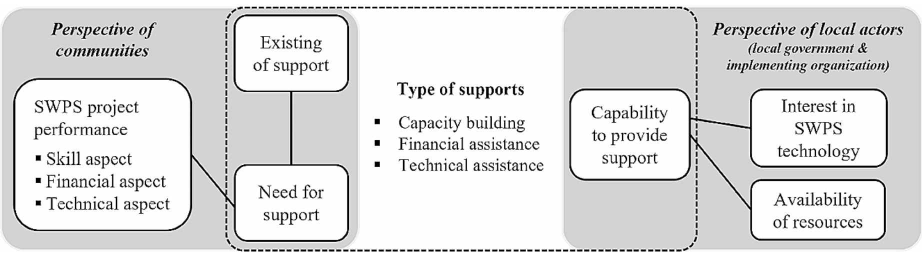


Fig. 1 Analytical framework

Table 1 Variables of analysis in the perspective of communities

Variables	Description	Scale of assessment
SWPS project performance		
Skill aspect		
• Performance of CBO	CBO capability in SWPS operational	1 = very bad to 4 = very good
• Sufficient training	Sufficiency of training to gain skills	1 = very not sufficient to 4 = very sufficient
• Solve problems independently	CBO ability to solve problems independently	1 = very not capable to 4 = very capable
Financial aspect		
• Willingness to pay	Willingness to pay for user fee	1 = very not agree to 4 = very agree
• Affordability	Affordability of service fee	1 = very not affordable to 4 = very affordable
• Incentives for CBO	Willingness to pay for CBO's incentives if any	1 = very not agree to 4 = very agree
Technical aspect		
• Frequency of using SWPS	Frequency of using water from SWPS	1 = very rarely/once every 2–3 months or more, to 4 = very often, every week
• Water sufficiency	Sufficiency of water for household consumption	1 = very insufficient to 4 = very sufficient
• Ease of use	Ease of using SWPS	1 = very not satisfied to 4 = very satisfied
• Ease of maintenance	Ease of conducting maintenance	1 = very not satisfied to 4 = very satisfied
• Technology durability	Technology durable for a long time	1 = very not satisfied to 4 = very satisfied
Existing of support		
Capacity building	Existing of support regarding the variables	1 = very rarely/1–2 times a year to 4 = very often/once a month
Financial assistance		
Technical assistance		
Need for support		
Capacity building	Need of support regarding the variables	1 = very not important to 4 = very important
Financial assistance		
Technical assistance		

Table 2 Variables of analysis in the perspective of local actors

Variables	Description	Scale of assessment
Preference of support model	Preference in support model demand-driven or supply-driven approach	N/A
Interest in SWPS technology	Interest to SWPS technology in comparison with diesel pumps	1 = not interested and 2 = interested
Availability of resource	The availability of resources (comprises funding, knowledge, data, access to materials, personnel, time, and incentives)	1 = not available and 2 = available
Capability to provide support	The capability to provide support with regard to the variables	1 = not capable and 2 = capable
• Capacity building		
• Financial assistance		
• Technical assistance		

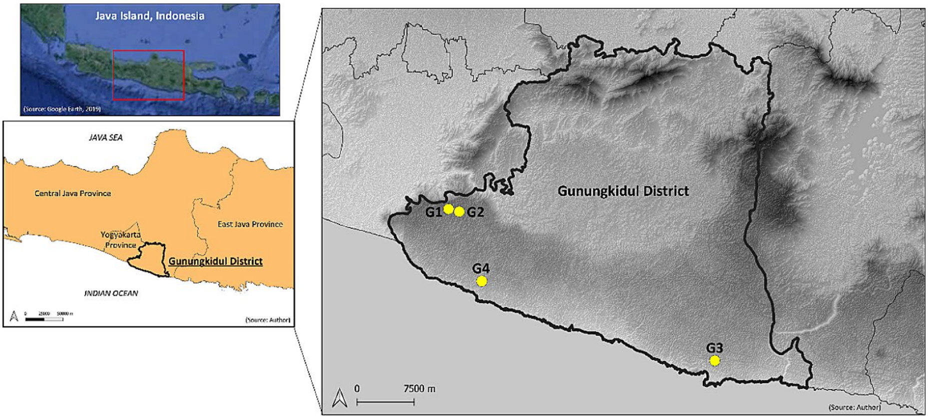


Fig. 2 Map of study area. *Source*: Author

Table 3 Project location and number of samples

Project initials	Implementing organizations	Years operating	Beneficiaries (household)	Sample (house-hold)
G1	NPO and international donors	4 years (2014–2018)	80	67
G2	NPO and national agency	5 years (2014–2019)	80	65
G3	University and NPO	1 years (2016–2016)	180	123
G4	University and NPO	3 years (2017–2021)	22	20

certain area, often far from water sources or springs. In remote neighborhoods without a water utility network, the common method to obtain water is by buying it in a water truck (5-m^3 tank) from private sellers at approximately 3 USD/m^3, which is expensive. Other methods include harvesting rainwater and collecting water directly from springs using a jerrican (a narrow flat-sided container for liquids). Hence, a decentralized energy–water system is considered appropriate for such neighborhoods (Fig. 2).

Several implementing organizations have initiated community-scale SWPSs in rural districts since the 1980s (Rahmani et al., 2023). Projects that were operated in the study area last five years, from 2016 onwards, were chosen in this study, and four projects that fit the criteria were selected (Table 3). Communities participated in all the projects during the development process. After construction was completed, management of the SWPSs, including the responsibility for their operation and maintenance, was entrusted to the CBOs. Currently, the systems are non-functional in three projects, namely G1, G2, and G3, whereas G4 is partially functional. Interviews with the CBOs revealed that the cause of malfunctions in all locations was faulty electrical components. In G1 and G2, damage was reported in the solar PV and pump, in G3 in the pump, and in G4 in the inverter.

4 Methodology

4.1 Sampling, data collection, and research variables

The data were collected using a questionnaire survey of communities or SWPS beneficiaries and local actors. The sample size of beneficiaries was set by considering the required accuracy level of the estimates and the resources needed to conduct the survey using the Yamane formula (Yamane, 1967). Accordingly, the sample size was estimated to be 273 people (one representative per household), and it was rounded off to 275 to ensure proportionate distribution within each study location (Table 3). Local actors were selected according to the local government of the district in which the project was located and the implementing organization that initiated the project. Table 4 presents a list of the local actors. The data were collected through the following two methods: (1) face-to-face questionnaire interviews with the communities, the head of the village, the head of the sub-district, and the district department and (2) written questionnaires that were sent via the Internet to the provincial agency and the implementing organizations. The method was chosen based on the convenience of the respondents.

The questionnaires for the beneficiaries were structured into the following four sections: (1) respondent profile; (2) SWPS performance: skill, financial, and technical aspects; (3) existing support; and (4) need for support. The questionnaires for the local actors comprised the following three sections: (1) preference for a support model, (2) interest in SWPS technology, (3) availability of resources, and (4) capacity to provide support. Data were gathered from July to October, 2021 with the help of five surveyors who received training before conducting the survey. The interviews and questionnaires were administered in Indonesia. This study was approved by the Tokyo Institute of Technology's Human Ethics Committee (Tokyo, Japan).

4.2 Data analysis

The data analysis comprised two parts according to the scope of the hypothesis: perspectives of the communities and local actors. Data from the community perspective were analyzed using four methods: (1) descriptive statistics, (2) chi-square test of independence, (3) principal component analysis (PCA), and (4) ordinal logistic regression. Descriptive statistics included frequencies, average values, and variances; it aims to interpret a dataset's characteristics through data distribution, central tendencies, and variability (Marshall & Jonker, 2010). The chi-square test of independence between two variables determines whether the variables (nominal or categorical) are independent or related, with the null hypothesis (H0) implying no relationship between them (Ho, 2006). In this analysis, using crosstab table, the relationship between two variables is identified in terms of their statistical significance in

Table 4 List of local actors

Local actors	Number of interviewees	Coded initials
Representative of province agency	1	PA
Representative of district department	2	DD1, DD2
Head of sub-district	2	SD1, SD2
Head of village	3	V1, V2, V3
Representative of implementing organizations	3	IO1, IO2, IO3

three categories: $p<0.01$ indicates a strong relationship (***), $p<0.011$ to $p<0.05$ implies a moderate relationship (**), and $p<0.051$ to $p<0.10$ indicates a weak relationship (*).

Two methods of multivariate analysis were used in terms of the community perspective: PCA and ordinal logistic regression. PCA aims to simplify many intercorrelated measures into a few representative constructs or factors. This is based on the assumption that all variables are correlated to some degree. Therefore, variables measuring similar underlying factors should have high correlations and those measuring dissimilar factors should have low correlations, resulting in a few representative factors that can be used for further analysis (Ho, 2006). Logistic regression is suitable for classifying variables into two or more categories based on a set of predictors. Regression analysis is suitable for models with binary or categorical dependent variables. However, the independent variables (predictors or determinants) in logistic regression can be both continuous and dichotomous (or categorical), making the method extremely flexible (Denis, 2019). In this study, the independent variables were the composite scores of the components extracted from PCA.

The local actors' data were analyzed using descriptive statistics and Fisher's exact test. This number of data points was relatively small, at only 11. Therefore, Fisher's exact test was employed for small datasets, as the chi-square test is typically invalid for small samples (Azen and Walker, 2011). The significance levels and hypotheses were similar to those of the chi-square test. Data processing was performed using Microsoft Excel for coding and cleaning, and data analysis was performed using SPSS v.25 (Fig. 3).

5 Results

This section describes the findings of the study. First, the results from the evaluation of the SWPS from the perspectives of communities are presented, followed by the perspectives of local actors.

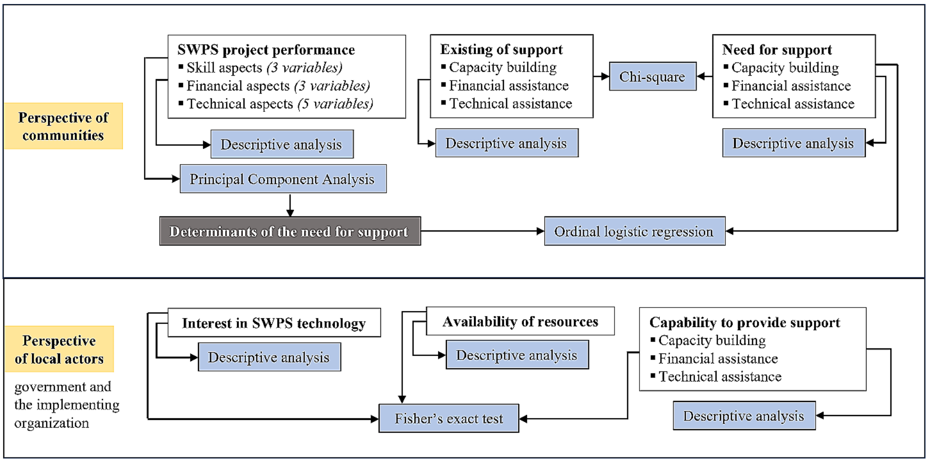


Fig. 3 Flowchart of research variables and method of analysis. *Note*: White box: research variables; blue box: method of analysis

5.1 Perspective of communities

This section comprises three parts: the profile of the surveyed households, community evaluation of the SWPS, and determinants of the need for support.

5.1.1 Profile of surveyed households

Most respondents were male (56%), 45–65 years old (51.6%), and had primary education (42.5%). Most of the surveyed households were employed in the agricultural sector (58.2%) and, on average, had a household size of 4.1 persons. The average household income was primarily between IDR < 400,000 and 800,000 (USD 28.14–56.28). This is below the standard minimum regional income of USD 124.18 per month. Table 5 presents the demographics of the surveyed households.

5.1.2 Evaluation of the SWPS from the community perspective

This section presents the results of the SWPS project performance from the community perspective. The scale of assessment ranged from 1 to 4, indicating very negative to very positive, according to each variable (Table 1). The results are presented as mean scores and standard deviations in Table 6.

Considering the skill aspect, the respondents perceived that the CBO performed inadequately in operating the SWPS (mean score = 2.46) and was incapable of solving problems independently (2.66). They also considered that the training conducted during project preparation was insufficient to gain skills (1.12). In terms of financial aspects, respondents were willing to pay (2.97) and agreed to pay for CBO incentives, if any (2.99). They considered the user fee for SWPS to be affordable (3.36).

From the technical aspect, the results show that the respondents (2.89) often used water from the SWPS when it was available, but they perceived that the water was insufficient for household consumption (2.26). Thus, they had to gather water from different sources to fulfill their household needs. These results reveal that while the user fee of the SWPS was cheap (for example, in G1 approximately 0.52 USD/m^3), the respondents incurred addi-

Table 5 Respondents' demographic

Variable	%	Variable		%
Sex		*Employment of household head*		
Male	56.0		Farmer	58.2
Female	44.0		Daily labor	14.9
Age			Entrepreneur	11.3
25–44	36.7		Construction labor	6.5
45–65	51.6		Others	9.1
> 65	11.7	*Average monthly household income (in IDR)*		
Education			< 400,000–800,000	50.2
Not finish primary school	12.4		810,000–1,200,000	20.0
Primary school	42.5		1,210,000–1,600,000	7.3
Junior high school	26.9		> 1,610,000	22.4
Senior high school and above	18.1	*Average household size (Std dev)*		4.1 (1.3)

Notes: 1 USD = 14,213 IDR (November 1, 2021).

Table 6 Descriptive statistics of the evaluation of SWPS project performance

Variables	Mean	SD
Skill aspects		
Performance of CBO	2.46	0.731
Sufficient training	1.12	1.402
Solve problems independently	2.66	0.540
Financial aspects		
Willingness to pay	2.97	0.178
Affordability	3.36	0.661
Incentives for CBO	2.99	0.104
Technical aspects		
Frequency of using SWPS	2.89	1.149
Water sufficiency	2.26	0.781
Ease of use	2.65	0.642
Ease of maintenance	2.33	0.563
Technology durability	2.22	0.559

Table 7 Descriptive statistics of existing support and the need for support

Variables	Mean	SD
Existing of support		
Capacity building	0.42	0.686
Financial assistance	1.12	1.135
Technical assistance	1.88	1.573
Need of support		
Capacity building	2.90	0.861
Financial assistance	3.20	0.984
Technical assistance	3.12	0.962

Table 8 Chi-square test of the need for support and the existing support

Variables	Need for support		
	Capacity building	Financial assistance	Technical assistance
Existing of support			
Capacity building	0.000***	0.000***	0.000***
Financial assistance	0.000***	0.000***	0.000***
Technical assistance	0.000***	0.000***	0.000***

Notes: *** implies significance at 0.01.

tional expenses to buy more water because the water supply from the SWPS was insufficient. This result also highlights a disadvantage of the SWPS, which is that the daily output depends on solar radiation. Considering the technical aspect, the mean score was below 3, indicating that the respondents were unsatisfied. Ease of use had a relatively higher score than ease of maintenance and technology durability (2.65, 2.33, and 2.22, respectively).

The statistical analysis results of the relationship between existing support and the need for support are presented in Tables 7 and 8. The results in Table 7 confirm that all types of existing support were significantly lower (mean existing capacity building, financial assistance, and technical assistance support=0.42, 1.12, and 1.88, respectively) than the corresponding need for support (mean need=2.89, 3.19, and 3.12, respectively). The chi-square test results in Table 8 show that the proportion of existing support differed significantly from that of the need for support. All variables in existing support were associated with the need for support ($p < 0.01$).

5.1.3 Determinants of the need for support

The analysis of these determinants consists of two steps: PCA and logistic regression. PCA was used to cluster the 11 variables of SWPS project performance into a few intercorrelated representative factors. The variables derived from the PCA results were then applied to a logistic regression analysis to predict the determinants of the need for support.

In the first step, a PCA with Kaiser-Varimax rotation was conducted to maximize the variance of the squared loadings, which are the correlations between factors and variables. This resulted in a smaller number of variables with high factor loadings, whereas the rest had low factor loadings. Consequently, a few key variables were identified for interpretation (Glen, 2023, n.d). Components are considered significant only if their eigenvalues are equal to 1 or higher. An eigenvalue represents the proportion of common (shared) and specific (unique) variances explained by an extracted component. An eigenvalue greater than 1 implies that the component explains a larger proportion of the common variance than that of the unique variance (Ho, 2006).

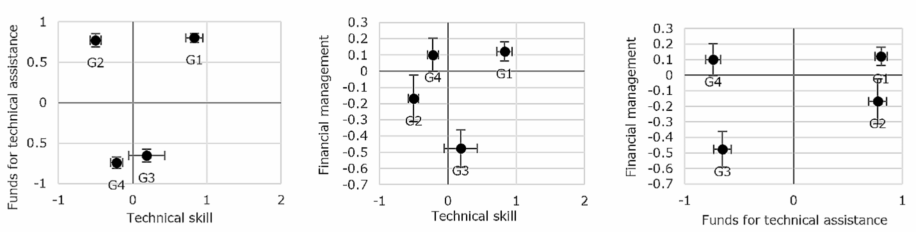
The PCA requirements, including the Kaiser–Meyer–Olkin measure of sampling adequacy (KMO > 0.5) and Bartlett's test of sphericity (significant at $p < 0.05$), were met by the variables. From the PCA, three components (eigenvalue > 1) that explained 51.2% of the variance were extracted, as shown in Table 9. Component 1, labeled technical skills, had the highest total variance (26.3%), indicating that it represented the largest fraction of the dataset. Component 2 was labeled funds for technical assistance and Component 3 was labeled financial management.

Subsequently, the composite score (REGR factor score) obtained from each component in the PCA was used to describe each project location. Figure 4 displays a scatter plot of the

Table 9 Rotated component matrix

Variables	Component			Label
	1	2	3	
(T) Ease of maintenance	*0.758*	0.204	0.039	Component 1: Technical skill
(T) Technology durability	*0.708*	−0.042	−0.007	
(T) Ease of use	*0.660*	0.212	−0.086	
(S) Performance of CBO	*0.644*	0.162	0.286	
(T) Frequency of using SWPS	0.116	*0.851*	0.036	Component 2: Funds for technical assistance
(T) Water sufficiency	0.210	*0.805*	0.113	
(F) Affordability	−0.092	*−0.594*	0.104	
(S) Sufficient training	0.244	−0.031	*0.529*	Component 3: Financial management
(S) Solve problem independently	0.335	0.218	*0.394*	
(F) Willingness to pay	−0.002	0.372	*−0.589*	
(F) Incentives for CBO	0.267	−0.132	*−0.682*	
Eigenvalue	2.896	1.515	1.230	
Variance (%)	26.329	12.769	11.178	
Cumulative (%)	26.329	40.098	51.276	

Note: (T), technical; (S), skill; (F), financial. Extraction method: principal component analysis. Rotation method: Kaiser-Varimax rotation.



(A) Technical skill and funds for technical assistance

(B) Technical skill and financial management

(C) Funds for technical assistance and financial management

Fig. 4 Mean of composite factor scores presented in each project location

Table 10 Logistic regression of dependent variable: capacity building

		Estimate	S.E.	Wald	df	Sig.	95% C.I.	
							Lower	Upper
Thres-hold	[Need_capacity=0]	–2.850	0.255	124.992	1	0.000	–3.349	–2.350
	[Need_capacity=2]	–2.683	0.240	124.640	1	0.000	–3.154	–2.212
	[Need_capacity=3]	2.321	0.222	109.466	1	0.000	1.886	2.756
Loca-tion	Technical skill	0.784	0.165	22.722	1	0.000***	0.462	1.107
	Funds for technical assistance	–0.148	0.151	0.959	1	0.327	–0.443	0.148
	Financial management	0.335	0.149	5.048	1	0.025**	0.043	0.628

Note: Final model fitting information: $p=0.000$; goodness-of-fit: Pearson chi-square test: $p=0.397$; deviance test: $p=1.000$; Nagelkerke's $R^2=0.137$.

mean scores with their standard errors. The results revealed that project G1 had relatively higher mean scores for all factors than the other locations. Project G2 had positive mean scores in terms of funds for technical assistance, whereas projects G3 and G4 had low scores. Furthermore, projects G2 and G4 had negative mean scores in terms of technical skills, whereas project G3 had slightly higher scores.

In the second step, a logistic regression was performed to identify the factors that significantly influenced the need for support. The composite scores of the three extracted components (technical skills, funds for technical assistance, and financial management) from PCA were considered as independent variables. The dependent variable was the need for support in capacity building, financial assistance, and technical assistance.

The logistic regression model calculates the maximum likelihood estimates using an iterative process. Herein, several pseudo R^2 values, including the Cox and Snell R^2 and Nagelkerke R^2, were used to evaluate the fit of logistic models (UCLA Statistical Consulting Group, 2011). The Cox and Snell R^2 had a maximum value lower than 1. Nagelkerke R^2 is a modified version of Cox and Snell R^2 and is usually preferred because it covers the entire range from 0 to 1 (Bewick et al., 2005).

All results suggested a good model fit, including final model fitting information ($p<0.05$) and goodness-of-fit ($p>0.05$). Tables 10 and 11, and 12 presents the regression results for the three extracted components. Significance levels of $p<0.05$ and $p<0.01$ are indicated by (**) and (***), respectively.

Table 10 shows that technical skills and financial management are significant determinants of the need for support in capacity building. Both factors positively correlated with

Table 11 Logistic regression of dependent variable: financial assistance

		Estimate	S.E.	Wald	df	Sig.	95% C.I.	
							Lower	Upper
Thres-hold	[Need_financial=0]	−2.763	0.247	124.970	1	0.000	−3.247	−2.278
	[Need_financial=1]	−2.702	0.241	125.644	1	0.000	−3.174	−2.229
	[Need_financial=3]	0.456	0.128	12.735	1	0.000	0.206	0.707
Loca-tion	Technical skill	0.436	0.124	12.359	1	0.000***	0.193	0.679
	Funds for technical assistance	−0.308	0.123	6.220	1	0.013**	−0.549	−0.066
	Financial management	0.141	0.123	1.325	1	0.250	−0.099	0.382

Note: Final model fitting information: $p=0.000$; goodness-of-fit: Pearson chi-square: $p=0.607$; deviance test: $p=1.000$; Nagelkerke's $R^2=0.137$.

Table 12 Logistic regression of dependent variable: technical assistance

		Estimate	S.E.	Wald	df	Sig.	95% C.I.	
							Lower	Upper
Thres-hold	[Need_technical=0]	−2.783	0.249	124.993	1	0.000	−3.271	−2.295
	[Need_technical=1]	−2.722	0.243	125.642	1	0.000	−3.197	−2.246
	[Need_technical=2]	−2.663	0.237	126.079	1	0.000	−3.128	−2.198
	[Need_technical=3]	0.783	0.135	33.844	1	0.000	0.519	1.046
Loca-tion	Technical skill	0.329	0.124	7.030	1	0.008**	0.086	0.572
	Funds for technical assistance	−0.476	0.127	13.934	1	0.000***	−0.726	−0.226
	Financial management	0.099	0.123	0.638	1	0.425	−0.143	0.340

Note: Final model fitting information: $p=0.000$; goodness-of-fit: Pearson Pearson chi-square: $p=0.946$; deviance test: $p=1.000$; Nagelkerke's $R^2=0.091$.

the need for support. In terms of financial and technical assistance, as shown in Tables 11 and 12, the determinants were technical skills (positive correlation) and funds for technical assistance (negative correlation). An example of this interpretation is as follows. Considering the dependent variable of the need for technical assistance, for an increase in technical skills by one unit, we expected an increase of 0.329 unit in the log odds of the need for technical support, provided that the other variables in the model were constant. Based on a similar assumption, for a decrease in funds for technical assistance by one unit, an increase of 0.476 unit in the log odds of the need for technical assistance was expected. The threshold values are generally not used during interpretation (UCLA Statistical Consulting Group, n.d.).

5.2 Perspective of local actors

All local actors perceived a demand-driven support model as more suitable than a supply-driven one for their institutional resources (Table 13). The interest score was relatively high for all actors, which indicates that they considered SWPS technology as attractive (mean = 1.83). In terms of the availability of resources and capacity for support, the implementing organizations had the highest score among other actors (1.67 and 1.89, respectively).

The Fisher's exact test (Table 14) was used to assess the relationships between capacity and interest, and capacity and resource availability. Although descriptive statistics revealed that the local actors showed a relatively high interest in the SWPS, it was not substantially

Table 13 Descriptive statistics of interest, availability of resources, and capability to provide support

Local actors	Preference of support model	Interest in SWPS technology	Availability of resources		Capability to provide support	
			Mean	SD	Mean	SD
Province agency (PA)	Demand-driven	2.00	1.29	0.49	1.00	0.00
District departments (DD1, DD2)	Demand-driven	1.50	1.21	0.43	1.33	0.58
Sub-district (SD1, SD2)	Demand-driven	2.00	1.07	0.19	1.00	0.00
Village (V1, V2, and V3)	Demand-driven	1.67	1.52	0.52	1.22	0.38
Implementing organizations (IO1, IO2, IO3)	Demand-driven	2.00	1.67	0.48	1.89	0.19

Note: Codes inside parentheses represent the initials of local actors, as described in Table 2.

Table 14 Fisher's exact test between the capability of support, interest, and resources

Variables	Capability to provide support		
	Capacity building	Financial	Technical
Interest	1.000	1.000	0.455
Resources			
Funding	1.000	0.491	0.455
Knowledge	0.015**	0.194	0.545
Data	0.545	1.000	1.000
Access material	0.545	0.576	0.242
Personnel	0.242	1.000	0.080*
Time	1.000	0.236	0.545
Incentives	1.000	1.000	0.455

Note: ** and * imply statistical significance at $p<0.05$ and $p<0.10$.

associated with the capacity to provide support. Instead, the two resource variables were related to the capacity to provide support. The results confirmed that knowledge was associated with the capacity for support in terms of capacity building and that personnel were related to the capacity to provide technical assistance.

6 Discussion

This study examined the support dimension for an SWPS in terms of the community's and the local actors' perspectives. Three types of support aspects were assessed: capacity building, financial assistance, and technical assistance. From the community perspective, as shown by the chi-square test, the existing support was inadequate and did not meet the need for support. PCA revealed three factors that determine the need for support: (1) technical skills, (2) funds for technical assistance, and (3) financial management. A comparative analysis between the project locations was also conducted, revealing that project G1 had relatively higher scores than the other projects. Although not the focus of this research, this analysis can determine the limiting aspects and the types of support that are crucial to a project. The findings of this study are first presented in this section, followed by relevant explanations and literature.

The results show that technical skill is a significant determinant because it relates to the need for all three types of support. Interviews with the CBOs who manage the SWPS revealed that this skill aspect was related to pump repair. Three of the four CBOs mentioned pumps as the most commonly malfunctioning elements of the system. This confirms a mismatch between advanced RE technology and the technical skills made available to communities. The principles of technological solutions in a community must fit the employment of local skills, financial resources, and material resources, such as the availability of spare parts (Short & Thompson, 2003). Implementing organizations and governments should consider the trade-off between the benefits of RE technology and the prerequisites of post-construction support to maintain the sustainability of the technology, particularly in rural areas. When support cannot be provided, the project's durability is at risk, which eventually hinders its sustainability and the associated socioeconomic benefits.

The results of the logistic regression analysis confirm that funds for technical assistance determine the need for financial and technical support. These findings show that funds collected from user fees may be insufficient for regular repairs. As shown in the descriptive statistics, the frequency of water use from the SWPS was high (60.7% of the respondents); therefore, regular appropriate maintenance should be implemented. Scheduled maintenance is directly related to the lifetime performance of SWPSs (Meah et al., 2008). However, the qualitative interviews revealed that in all projects, the reserve fund was insufficient to repair malfunctions. As stated by the CBO representatives, for project G1, "The reserve fund was insufficient for repairmen," and for project G4, "We do not have enough funds to purchase spare parts for replacement." This shows that the costs of repairs and spare-part replacements require a budget larger than the collection of service fees. Moreover, the daily output of an SWPS is typically insufficient for household consumption (58.9%), which may cause inconsistencies in the collected funds. Although the CBO could have held fundraisers recruiting users to cover maintenance costs (Meah et al., 2008), it was difficult because most users were farmers from low-income households. Therefore, although user fees are affordable and do not require subsidies, repairs may require additional financial assistance. Furthermore, the SWPS service fee may have to be increased to include the necessary reserve fund.

Logistic regression analysis also revealed that technical skills and financial management were the determinants of the need for support in capacity building. Community willingness to participate in and contribute to manpower is inadequate to ensure sustainability (Ibrahim, 2017). This is particularly true because, despite training provided to the CBO during project preparation, most of the respondents (50.6%) considered it insufficient to repair malfunctions independently. Thus, they stated that the CBO cannot solve the malfunctions independently.

From the perspective of local actors, we found that their interest in the SWPS does not relate to their capacity to provide support. They mentioned an interest in SWPS technology, mainly in terms of environmental protection. The reasons for limited interest include high capital costs (indicated by V2 and IO2, and the list of coded initials presented in Table 4), the requirement of high-maintenance and skilled technicians (DD1, DD2, SD2, and V3), and a high risk of vandalism (IO1). Regarding the availability of resources and capacity to provide support, the results confirmed that the implementing organizations had the highest score among the local actors. This is expected as the implementing organizations were the initiators of the SWPS projects, whereas the local governments have not yet installed an SWPS in Gunungkidul District (Table 3). Generally, the implementing organizations are expected to provide post-construction support, and the institutional arrangements (institutional mandate, responsibility, and financing) of local governments do not align with the development of the SWPS (Rahmani et al., 2023).

The findings demonstrate that the capacity of local actors to provide support is associated with available resources, particularly knowledge of capacity building and technical assistance personnel. Sufficiency of resources is a key factor influencing the provision of support (Miller et al., 2019). This study revealed that local actors perceived that the demand-driven model was a better fit with their institutional resources. This is expected as demand-driven support requires relatively fewer resources and operational expenditures than the supply-driven model (Nagel et al., 2015). In the case of implementing organizations and village governments (two actors that had relatively higher scores in the availability of resources), the resources were not specifically dedicated to providing support. For instance, the local actor indicated by V3 disclosed, "We are not interested in allocating a village budget for SWPS considering its durability, maintenance, and continuity of water supply." IO1 stated, "Our institution has limited human resources; hence, the demand-driven model is more suitable." Moreover, IO3 stated, "Our activities are related to community-based services; to procure funding, we have to prepare proposals for donors." Therefore, although resources are available, they do not serve specifically to support the existing SWPS, nor do they provide systematic support in practice.

Expecting continuous post-construction support from local actors is challenging because their resources are not always available, as previously discussed. We conclude that more effort should be dedicated to community capacity building during project construction to minimize the need for external support during project deployment. Hence, the community should be equipped with the capacity to independently manage SWPSs such as the ability to detect early malfunctions, access to service centers, and channels to repair components.

7 Conclusion

This study explored four SWPS projects in Indonesia to assess the post-construction support from the perspectives of communities and local actors. Three types of support were assessed: capacity building, financial assistance, and technical assistance. From the community perspective, a clear gap was observed in the existing support and the need for support in all these aspects.

This study identified three determinants of the need for support: technical skills, funds for technical assistance, and financial management. Technical skills are particularly important because they determine the need for all types of support. In particular, attention should be paid to the skills of pump maintenance and repair because, according to interviews with the CBO, this component frequently causes the system to shut down in most projects. From the perspective of local actors, SWPS is considered an interesting technology compared with diesel pumps. However, in terms of providing support for SWPSs, their capabilities are limited. Our analysis revealed that support provision was related to availability of institutional resources, such as knowledge and personnel, rather than interest in technology. Among other local actors, implementing organizations have relatively more resources and capacity to provide support. However, their dedicated resources for support were often unavailable, which prevented them from arranging for support.

These findings provide insights into the significance and role of the support dimension for achieving sustainability in local innovation in rural areas. The current system malfunction could not be handled by the local community and CBO owing to the lack of sufficient technical skills. However, relying on external actors is difficult, because their resources are not readily available. Our findings demonstrate a requirement for improving the capacity of the CBO to sustain technology at an early stage of project development. In addition to greater effort dedicated to increase communities' capabilities, RE project planning should be designed to consider and promote support from all stakeholders beyond project implementation, rather than technology orientation.

In this study, we did not focus on the categorization of system breakdown and repair management, which should be investigated in future research. The challenges reported in this study are not exclusive to the SWPS but are also faced by community-level management in areas with an RE system. Hence, our analytical framework can be useful in other cases that explore the gap in the support for an RE project. A sustainable paradigm must be implemented during project planning and management to facilitate continuous monitoring, evaluation, and support.

Appendix: content of questionnaires

Variables	Content of questionnaires
Questionnaire for community	
Sex	Sex of the respondent
Age	Age of the respondent
Education	Education of the respondent
Employment of household head	Main occupation of the household head
Average monthly household income	Average monthly household income
Average household size	Number of family member
Performance of CBO	How do you think about the performance of CBO in operating the SWPS?
Sufficient training	Do you think the training sufficed to gain the necessary skills and knowledge?
Solve problem independently	Do you think the CBO has enough skills and knowledge to solve problems independently?
Willingness to pay	Are you willing to pay for water service?
Affordability	What do you think about the affordability of the service fee of SWPS?
Incentives for CBO	Do you agree about the incentives (service management fee) for CBO?
Frequency of using SWPS	How often you used water from SWPS?
Water sufficiency	How was the sufficiency of the water for household consumption?
Ease of use	How do you think about SWPS in terms of ease of use?
Ease of maintenance	How do you think about SWPS in terms of ease of maintenance?
Technology durability	How do you think about SWPS in terms of durability?
Existing of support	How is the existing of support for SWPS regarding capacity building, financial assistance, and technical assistance?
Need of support	How is the need for support regarding capacity building, financial assistance, and technical assistance?
Questionnaire for local actors	

Variables	Content of questionnaires
Interest about SWPS technology	How do you think about SWPS compared with a diesel-powered system for water infrastructure?
Preference of support model	Among supply-driven and demand-driven models, which support model that you think best-suited with your institution capacity?
Availability of resources	How do you think your resources in terms of funding, knowledge, data, access to materials, personnel, time, and incentives?
Capability to provide support	How do you think your institution's capability to provide support regarding capacity building, financial assistance, and technical assistance?

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Declarations

Conflict of interest The authors report there are no competing interests to declare.

References

Azen, R., & Walker, C. (2011). *Categorical Data Analysis for the Behavioral and Social Sciences*. Routledge. https://doi.org/10.4324/9780203843611

Bannister, M. (2000). Solar Power for Community Water Supply. *26th WEDC Conference at Dhaka, Bangladesh: Water, Sanitation, and Hygiene: Challenges of the Millennium*, 311–314.

Bewick, V., Cheek, L., & Ball, J. (2005). Statistics review 14: Logistic regression. In *Critical Care* (Vol. 9, Issue 1, pp. 112–118). https://doi.org/10.1186/cc3045.

Chaudhuri, S., Roy, M., McDonald, L. M., & Emendack, Y. (2020). Water for all (Har Ghar Jal): Rural Water Supply Services (RWSS) in India (2013–2018), challenges and opportunities. *International Journal of Rural Management*, *16*(2), 254–284. https://doi.org/10.1177/0973005220946661.

Denis, D. J. (2019). *SPSS Data Analysis for Univariate, Bivariate, and Multivariate Statistics*.

Derks, M., & Romijn, H. (2019). Sustainable performance challenges of Rural microgrids: Analysis of incentives and Policy Framework in Indonesia. *Energy for Sustainable Development*, *53*, 57–70. https://doi.org/10.1016/j.esd.2019.08.003.

Dobravec, V., Matak, N., Sakulin, C., & Krajačić, G. (2021). Multilevel Governance Energy Planning and Policy: A View on Local Energy initiatives. *Energy Sustainability and Society*, *11*(1). https://doi.org/10.1186/s13705-020-00277-y.

Fudge, S., Peters, M., & Woodman, B. (2016). Local authorities as Niche actors: The case of Energy Governance in the UK. *Environmental Innovation and Societal Transitions*, *18*, 1–17. https://doi.org/10.1016/j.eist.2015.06.004.

Varimax Rotation: Definition. Retrieved September 4, from https://www.statisticshowto.com/varimax-rotation-definition/.

Hartmann, A., Goldscheider, N., Wagener, T., Lange, J., & Weiler, M. (2014). Karst Water resources in a changing world: Review of Hydrological modeling approaches. *Reviews of Geophysics*, *52*(3), 218–242. https://doi.org/10.1002/2013RG000443.

Hjalmarsdottir, E. H. (2012). Solar Powered Pumping Technologies in Rural Water Supply: Case Study from Kunene Region. *Namibia Waterlines*, *31*(3), 197–214. https://doi.org/10.3362/1756-3488.2012.021.

Ho, R. (2006). *Handbook of Univariate and Multivariate Data Analysis and Interpretation with SPSS*. Taylor & Francis Group.

Hong, G. W., & Abe, N. (2012). Sustainability Assessment of Renewable Energy Projects for off-grid rural electrification: The Pangan-an Island Case in the Philippines. *Renewable and sustainable energy reviews* (Vol. 16, pp. 54–64). Elsevier Ltd. 1https://doi.org/10.1016/j.rser.2011.07.136.

Ibrahim, S. H. (2017). Sustainability Assessment and Identification of Determinants in Community-based Water Supply projects using partial least squares path model. *Journal of Sustainable Development of Energy Water and Environment Systems*, *5*(3), 345–358. https://doi.org/10.13044/j.sdewes.d5.0153.

Ikejemba, E. C. X., Mpuan, P. B., Schuur, P. C., & Van Hillegersberg, J. (2017). The Empirical Reality & Sustainable Management Failures of Renewable Energy Projects in Sub-saharan Africa (part 1 of 2). *Renewable Energy*, *102*, 234–240. https://doi.org/10.1016/j.renene.2016.10.037.

IRC (2001). *From System to Service: Scaling up Community Management*. http://www.irc.nl.

Joshi, L., Choudhary, D., Kumar, P., Venkateswaran, J., & Solanki, C. S. (2019). Does involvement of Local Community ensure sustained Energy Access? A critical review of a solar PV technology intervention in Rural India. *World Development*, *122*, 272–281. https://doi.org/10.1016/j.worlddev.2019.05.028.

López-González, A., Ferrer-Martí, L., & Domenech, B. (2019). Long-term sustainability Assessment of Micro-hydro projects: Case studies from Venezuela. *Energy Policy*, *131*, 120–130. https://doi.org/10.1016/j.enpol.2019.04.030.

Lorentz (2021). *References in Indonesia*. www.lorentz.de/en/references/asia/indonesia/.

Marquardt, J., & Delina, L. L. (2019). Reimagining Energy futures: Contributions from Community Sustainable Energy Transitions in Thailand and the Philippines. *Energy Research and Social Science*, *49*, 91–102. https://doi.org/10.1016/j.erss.2018.10.028.

Marshall, G., & Jonker, L. (2010). An introduction to descriptive statistics: A review and practical guide. In *Radiography* (Vol. 16, Issue 4). https://doi.org/10.1016/j.radi.2010.01.001.

Meah, K., Ula, S., & Barrett, S. (2008). Solar Photovoltaic Water Pumping - opportunities and challenges. *Renewable and Sustainable Energy Reviews*, *12*(4), 1162–1175. https://doi.org/10.1016/j.rser.2006.10.020.

Mey, F., Diesendorf, M., & MacGill, I. (2016). Can local government play a Greater Role for Community Renewable Energy? A case study from Australia. *Energy Research and Social Science*, *21*, 33–43. https://doi.org/10.1016/j.erss.2016.06.019.

Miller, M., Cronk, R., Klug, T., Kelly, E. R., Behnke, N., & Bartram, J. (2019). External Support Programs to Improve Rural Drinking Water Service Sustainability: A Systematic Review. In *Science of the Total Environment* (Vol. 670, pp. 717–731). Elsevier B.V. https://doi.org/10.1016/j.scitotenv.2019.03.069.

Nagel, C., Beach, J., Iribagiza, C., & Thomas, E. A. (2015). Evaluating Cellular Instrumentation on Rural handpumps to improve Service Delivery-A Longitudinal Study in Rural Rwanda. *Environmental Science and Technology*, *49*(24), 14292–14300. https://doi.org/10.1021/acs.est.5b04077.

Primawan, A. B., & Iswanjono (2019). Solar Water Pumping System: Utilization of Solar Energy for Clean Water Provision in Karang Sub-village, Gunungkidul (in Indonesian). *ALTRUIS*, *2*(1), 38–43. https://doi.org/10.24071/altruis.2019.020106.

Rahmani, S., Murayama, T., & Nishikizawa, S. (2020). Review of Community Renewable Energy Projects: The Driving Factors and Their Continuation in the Upscaling Process. *IOP Conference Series: Earth and Environmental Science*, *592*(1). https://doi.org/10.1088/1755-1315/592/1/012033.

Rahmani, S., Murayama, T., & Nishikizawa, S. (2021). Socio-economic impact of a Solar Water Pumping System in a Rural Community in Indonesia. *Journal of Sustainable Development of Energy Water and Environment Systems*, *N/A*(N/A), 0–0. https://doi.org/10.13044/j.sdewes.d9.0403.

Rahmani, S., Murayama, T., Nishikizawa, S., & Roychansyah, M. S. (2023). Local Governance of Sustainability Transition in Community-Scale Solar Water Pumping systems in Indonesia. In A. Triyanti, M. Indrawan, L. Nurhidayah, & M. A. Marfai (Eds.), *Environmental governance in Indonesia* (pp. 439–461). Springer.

Salis, F. R., Pranadi, A. D., Budiarto, R., Aliyah, F., & Novitasari, D. (2018). Comprehensive Education of RES in Rural Karst Area: Sustainable Development of Solar Water Pumping System in Banyumeneng Village, Yogyakarta, Indonesia. *International Journal of Electrical Energy*, *6*(2), 74–78. https://doi.org/10.18178/ijoee.6.2.74-78.

Short, T. D., & Thompson, P. (2003). Breaking the Mould: Solar Water Pumping - the challenges and the reality. *Solar Energy*, *75*(1), 1–9. https://doi.org/10.1016/S0038-092X(03)00233-0.

Terrapon-Pfaff, J., Dienst, C., König, J., & Ortiz, W. (2014). A cross-sectional review: Impacts and sustainability of small-scale renewable Energy projects in developing countries. *Renewable and Sustainable Energy Reviews*, *40*, 1–10. https://doi.org/10.1016/j.rser.2014.07.161.

The World Bank (2009). *Post-construction Support and Sustainability in Community-managed Rural Water Supply*.

UCLA: Statistical Consulting Group. (n.d.). *Ordinal Logistic Regression: SPSS Data Analysis*. California: University of California Los Angles. Retrieved December 22 (2021). from www.stats.oarc.ucla.edu/spss/dae/ordinal-logistic-regression/.

UCLA: Statistical Consulting Group (2011). *FAQ: What are pseudo R-squareds?*https://stats.oarc.ucla.edu/other/mult-pkg/faq/general/faq-what-are-pseudo-r-squareds/.

UNESCAP (1991). *Solar-powered Water Pumping in Asia and the Pacific*.

Usman, S. (2001). *Indonesia's Decentralization Policy: Initial Experiences and Emerging Problems*.

Usman, Sunding, A., & Parawangsa, A. N. (2018). Analisis Kinerja Dan Ekonomi Sistem Pompa Air Tenaga Surya Skala Laboratorium (in Indonesian). *Jurnal Teknologi Terapan*, *4*(1).

Wahyuni, N. S., Wulandari, S., Wulandari, E., & Pamuji, D. S. (2015). Integrated Communities for the Sustainability of Renewable Energy Application: Solar Water Pumping System in Banyumeneng Village, Indonesia. *Energy Procedia*, *79*, 1027–1032. https://doi.org/10.1016/j.egypro.2015.11.604.

Yamane, T. (1967). *Statistics: An Introductory Analysis*.

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