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Abstract

Mountainous hinterland in rural Nepal lacks fundamental social infrastructure. Lack of electricity causes difficulty of water provision, especially in mountainous area where villagers, especially ladies, youths and children, often spends large amount of time just to convey water. To overcome this challenge, a subsidy policy on installation of solar-photovoltaic water pumping system (SWPS) is recently being implemented nation-wide in Nepal. Confrontation of the Nepali government with her tight financial constraint requires the installation process be both economically and technologically sound. However the institutional design of the current subsidization policy is price-distortionary and potentially inducing installation of inefficient systems. By collecting original field data from 38 wards in all seven regions in the entire Nepal, this paper thus measures the technical efficiencies of SWPS, and then identifies relevent economic policies that will enhance the performance of SWPS. Our results show, inter-alia, that higher dependency on financial support from the government indeed results in excessive investment on SWPS.

Keywords: solar water pumping system, rural development, data envelopment analysis

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1 Introduction

Geographically-challenged mountainous hinterland in rural Nepal faces severe underdevelopment problems due to lack of fundamental social infrastructure. Electricity infrastructure in Nepal is far less than what is sufficient. On-the-grid electrification rate for the entire Nepal is as low as 55%, and is significantly lower for rural areas.[1] Due to the frequent blackouts, water provision that does not depend on electricity is widely utilized even in the capital city of Katmandu. Lack of electricity causes difficulty of water provision especially in mountainous area where the altitudinal variation is large both to the water source and within a community. In the mountainous area of Nepal few cases of electricity generation by solar panels or a micro water-power generator exists, however, water supply mostly depends on human labor. Villagers, especially ladies, youths and children, often spends large amount of time just to convey water to their families everyday. To overcome this challenge, installation of solar-powered water provision systems (so-called Solar-photovoltaic Water Pumping System or, SWPS) as an essential labor-saving technology is recently being implemented and expected to spread nation-wide in Nepal.[2]

Alternative Energy Promotion Center (AEPC) under Ministry of Environment in Nepal estimates potential demand for SWPS to be around 1,500 villages. The first case of SWPS installation dates back to 1982, however, the total number has not grown as fast since then. It is only recently that AEPC started a policy in the form of matching subsidy for partly covering the initial cost of SWPS. Confrontation of the Nepali government with her tight financial constraint requires the installation process be both economically and technologically sound. Finding an efficient way of promoting installation of SWPS through the subsidy policy is thus an acute research agenda, both from technical and social points of view. By collecting original field data from 38 wards in all seven regions in the entire Nepal, this paper thus identifies the technically efficient cases of SWPS, and then investigates any potential economic policy that will enhance the performance of SWPS.

We take a two-stage approach to attain this objective. In the first stage we conduct the data envelopment analysis (DEA) to measure the productive efficiency of SWPS in each village, defined as the actual number of households that are served by SWPS relative to the number predicted by the sizes of inputs such as tank capacity, distribution pipe length, and solar panels' peak kilo watts. The obtained efficiency scores are then attributed to the differences in institutional settings as well as technical design of the system. Our results show, inter-alia, that abundant financial support from the government results in inefficient systems, and that charging user fees significantly discourages villagers' participation to SWPS and hence undermines the potential benefit of SWPS.

To date, there is no existing research investigating the efficiency of SWPS and its social and technical determinant factors. Closest will be by Campana, Li, and Yan (2013) who analyzed an efficient design of SWPS with more emphasis on technical aspects such as type of electric current and photovoltaic array, rather than the social factors. Shrestha (2001) provides a descriptive study using observations on SWPS in three villages, and draws policy suggestions for specific cases based on the experiences in these three villages. Thus far there are only 88 cases of SWPS installation with governmental or other external support. Moreover, it usually takes several days to access the villages in the mountain side of Nepal for data collection. Given this circumstances, this paper provides the first quantitative analysis using geographically comprehensive data consisted of observations on 38 villages across all seven regions in Nepal on the efficient design and policy of SWPS.[3]

We start by reviewing the social background as well as Nepali government's current policy concerning the SWPS promotion in the next section. Then Section 3 presents the methodology of empirical analysis, followed by the description of data and obtained results in Section 4. Finally, Section 5 concludes.

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[1] Even including the off-grid micro power generators, the figure rises only to 69%.

[2] SWPS is a composite package of drawing water from alternative sources to a distribution tank using photovoltaic energy, which is then connected to community taps by using the gravity force. According to Oki et. al. the time saving due to installation of SWPS is average 70 minuites, and it could be as large as five hours a day.

[3] We conducted a field survey on 44 villages with SWPS installation cases, of which six utilized an aid by international organizations and/or NGOs, instead of government support.

2 Social Background and Subsidy Program of the SWPS in Rural Nepal

2.1 Rural Water Supply in the Disadvantaged Mountainous Areas of Nepal

Access to sustainable and convenient water supply is vital to improve the livelihoods of rural populations. People living in the mountainous areas of Nepal particularly face difficulties to obtain drinking water supply. They are urged to walk long distances alongside the hilly mountains, while bring large quantity of water tanks. It sometimes takes hours to walk to the water sources, and bring back to their houses. This is not only a tedious activity to perform every day, but also a waste of useful time that can be alternatively invested in other productive activities. Since drawing up water is usually carried out by women and children, it raises the social issues to be accounted for development challenges.

Easy access to drinking water supply significantly changes the quality of rural livelihoods. Water pumping systems which is driven by diesel energy or grid-connected electricity power enable rural villagers to have improved water accessibility. Although diesel or electricity driven facilities are not universally suitable tools for remote mountainous areas of Nepal. Firstly it is quite costly to purchase sufficient amounts of diesel for rural people whose cash income is negligible. Carrying diesel fuels to mountain areas imposes higher transportation costs due to weak infrastructures which results in expensive as well as irregular supplies.

Moreover, rural areas have suffered from a lower electrification ratio, with urban electrification at 97.0% and rural electrification at 71.6% in Nepal (IEA 2012). Even in the grid-connected areas, power breakdown is frequent phenomena due to insufficient electricity supply that corresponds to recent growing electricity demand. Almost all of electricity generation is based on hydropower, however, generation capacity is limited especially in the winter seasons when water quantity and flow velocity is limited. Accounting to the current insufficient generation capacity, it is unrealistic to predict stable electricity supply for remote mountainous and poor areas for the purpose of improving drinking water supply.

Solar-photovoltaic water pumping systems, or SWPS are one of alternatives and promising tools for serving improved water supply for disadvantaged areas and greatly improve the livelihoods of rural settlers. SWSP is comprehensive packages that contain 1) solar photovoltaic arrays, 2) water storage tanks located nearby water sources (e.g. river, stream, ponds, rivulet etc), 3) distribution tanks for storing water that has been pumped up by electric power, 4) water pumps for drawing up from storages to distribution tanks, 5), community taps for water distribution, and other auxiliary equipments and facilities. Water from distribution tanks are delivered through community taps located in the village. Capacities of tanks and solar photovoltaic modules differ according to the number of beneficiaries. Villagers are free from walking long distances in the hilly mountains to water sources, and can fetch water from respective taps nearby from their houses. Since water availability is influenced by solar radiation, water is not always accessible from the taps especially in the rainy seasons. Still SWPS is not a perfect solution for improving water access, villagers can enjoy better livelihoods through reduction of efforts for drawing water.

2.2 Policy Schemes for Promoting Installations of SWPS

Since costs of installing SWPS become enormous, external funding for facilitating installation is necessary. Under the supports of donor agencies, Alternative Energy Promotion Center (APEC), an government agencies under Ministry of Science, Technology, and environment, have played a role of executing agency to proliferate the SWPS all over the country. The first SWPS was installed in 1992, and has expanded to around 100 systems so far in various regions of Nepal.[4]

Currently AEPC provides the subsidies at the maximum of 75% of total construction costs but not exceeding 1.5 million rupee (recently increased from 1 million rupee) for each SWPS which pass technical feasibility assessments including geographical conditions, social consideration (economic status, community mobilization, and maintenance), and financial capabilities to cover remaining costs uncovered by the subsidies. The areas which are connected by the grid electricity are also excluded from eligible sites.[5]

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[4] Note that NGOs or external funding agencies built SWPS outside the government initiatives, however, its exact numbers and specification of SWPS are unclear.

[5] The details of subsidy policy for renewable energies including solar PV energy is summarized by Gurung et al. (2012).

Here are the common procedures for installing SWPS. Firstly, the local villagers are required to submit applications form for APEC. As villagers have little knowledge on SWPS itself and its modalities, usually regional service centers (external cooperative agencies of AEPC) and NGOs are closely involved in developing application documents. Based on the submitted applications, detailed feasibility study is carried out by respective regional centers appointed by AEPC. Since 25% of total costs should be raised by villagers, mutual agreements on allocating financial burdens among the perspective beneficiaries are critically important. Financial burdens are covered by collecting cash from villagers, in-kind contribution in the form of labor supports, or funding from local governments (Village Development Committee). After approval by the committee in APEC, private solar companies recruited by the competitive biddings initiate construction. Role of communities are enormous for ensuring sustainability of SPWS projects; such as deciding the rules of using water, recruiting personnel engaging maintenances, collecting fees for maintenances.

2.3 Theoretical Foundation of the Potential Institutional Failure Causing Excessive SWPS Capacity Investment

Let us consider a village with N households, each earning an exogenous income of y that will be spent on SWPS water and a numeraire composite good z. Denoting SWPS water consumption quantity per household by q and its price by p, we then describe household's utility u and its budget constraint as

$$\begin{aligned} u &= u(z,q) \\ y &= z + pq \end{aligned}$$

where q is assumed to be a normal good.

Let Q be the capacity of SWPS installed in this village, and $C(Q)$ be its total cost. Now the government provides ad-valorem subsidy S with its rate being α and its maximum amout being $\bar{S}$. Then we have

$$S = \min\left\{\alpha C(Q), \bar{S}\right\}$$

and a resource constraint such that

$$C(Q) = pQ + S.$$

Here, let us assume for simplicity that households are homogeneous and that the total cost function is such that the marginal cost is constant with a fixed cost. These imply that $C(Q) = cQ + F$ where c and F are marginal and fixed costs respectively and that by homogeneity of households, $Q = Nq$. Define f as the fixed cost per household i.e., $f = F/N$. Collective decision of this village then reduces to the following welfare maximization problem subject to the resource constraint, all expressed in the per-household terms:

$$\begin{aligned} \max_{z,q} \quad & u(z,q) \\ s.t. \quad & y + s = z + cq + f \end{aligned}$$

where $s = S/N$ being the subsidy per household and hence $s = \min\{\alpha(cq+f), \bar{s}\}$.[6] Solving this yields the following:

$$\frac{u_q}{u_z} = \begin{cases} (1-\alpha)c & \text{if } q < \tilde{q} \\ c & \text{if } q > \tilde{q} \end{cases}$$

and if $q = \tilde{q}$ then $u_q/u_z \in [(1-\alpha)c, c]$, where $\tilde{q} = (\bar{s}/\alpha - f)/c$.[7]

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[6] Obviously we define $\bar{s} = \bar{S}/N$.

[7] We assume an interior solution with y being sufficiently larger than f.

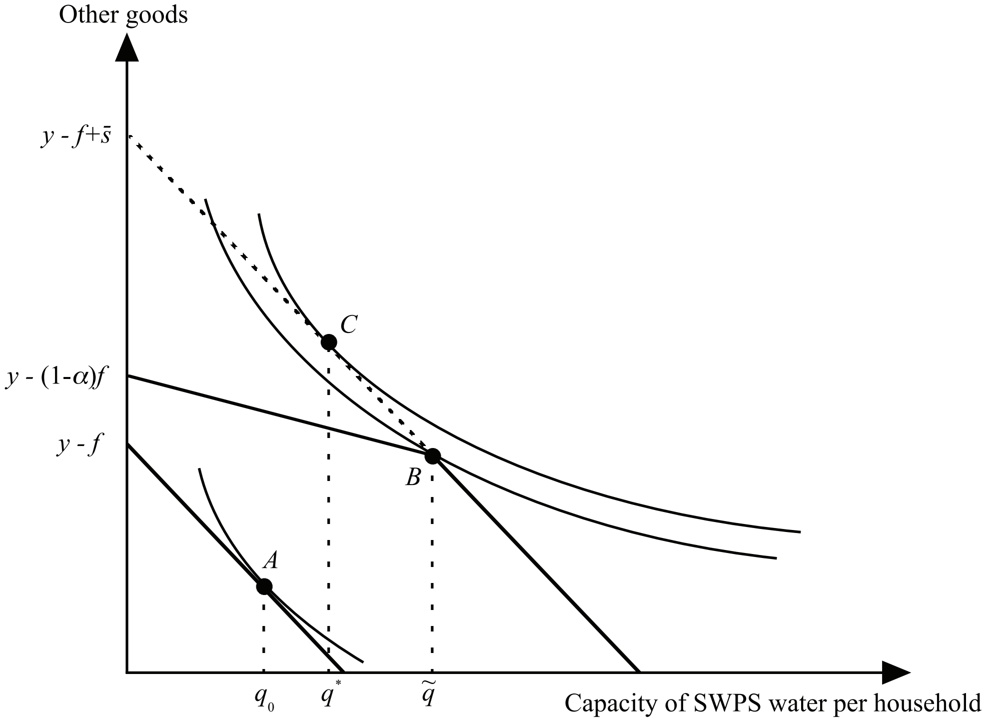

Figure 1
Institutional failure and a potential overinvestment in SWPS capacity.

The situation where $u_q/u_z \in [(1-\alpha)\,c, c]$ with $q = \tilde{q}$ is depicted in Figure 1. Without the subsidy the village decision in per-household terms is at A in the diagram. With the ad-valorem subsidy the collective decision moves their choice to B, where the indifference curve is not tangent, but going through the kink on the resource constraint. In this situation the village is receiving the maximum amount of subsidy $\bar{S}$. However, the lump-sum principle tells that should this amount $\bar{S}$ be simply given to the villagers, they achieve higher utility at point C for the same financial burden of the government. Hence the ad-valorem subsidy excessively encourages the SWPS capacity to be larger, as much as the difference between $\tilde{q}$ and q^*.

Obviously, this inefficiency does not emerge when the choice under this subsidy program is such that the indifference curve is tangent to the resource constraint somewhere to the right of the kink (point B) in the figure. Chances are that this is the case if the village income y is sufficiently large relative to $\bar{s}$, and better yet if the village population is large so that f, per-household fixed cost is relatively small. Note that these larger, richer villages as a result have a lower share of subsidy in the total cost of SWPS installation. Conversely, poorer, smaller villages with higher dependency on subsidy have higher tendency to install a system that is too large in terms of per-household capacity. We will in what follows verify this postulation by measuring the productive efficiency of SWPS in terms of the number of households served relative to its capacity at the village level, and then by attributing such efficiency to the social factors and village characteristics.

3 Methodology of SWPS Performance Measurement and Evaluation

We first estimate the productive efficiency of SWPS at the village level in rural Nepal using the data envelopment analysis (DEA). Obtained efficiency scores are then regressed on social and technical factors to investigate their impact on and potential improvement in the efficiency of the system. Social factors include the amounts of user charges and governmental subsidies as well as initial installation cost per household. Technical factors are the extent of variations in water sources, access to technical consultancy in the stage of system design, and capacity of the collection tanks as well as its cross term with the distribution tank capacity.

3.1 Measurement of the SWPS Productive Efficiency at the Ward Level

We employ the output-oriented DEA to assess the technical efficiency of the SWPS in 38 villages (i.e., wards) in rural Nepal.[8] Output-oriented DEA measures the productive efficiency of a decision making unit (DMU) as the relative distance to the production possibility frontier in the direction of output expansion. Specifically the efficiency of the kth DMU is defined as the maximum value of h_k in the following linear programming problem:

$$\begin{aligned} & \max_{\lambda_1,\cdots,\lambda_K} h_k \\ s.t. \quad & \sum_{\kappa=1}^{K} \lambda_\kappa y_{i\kappa} = h_k y_{ik} \ \forall i = 1,\cdots,N \\ & \sum_{\kappa=1}^{K} \lambda_\kappa x_{j\kappa} = x_{jk} \ \forall j = 1,\cdots,M \\ & \sum_{\kappa=1} \lambda_\kappa = 1 \end{aligned} \tag{1}$$

where x_{jk} is the jth input and y_{ik} is the ith output of the kth DMU respectively. The last line of the above problem (1) enters as we assume variable return to scale of production. For CRS productive efficiency such restriction and not present, and by taking the ratio to VRS efficiency ob it one can obtain the scale efficiency. Figure 2 illustrates the measurements of DEA efficiency scores in a case of one output and one input.

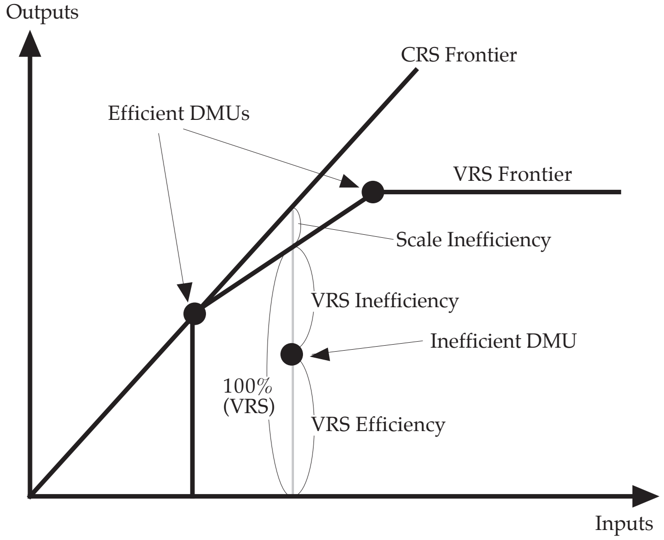

Figure 2
Illustration of the DEA efficiency measurement method.

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[8] DEA is widely used in efficiency measurement of ranging industries and economies. Tanguchi and Kaneko (2009) estimated the operational efficiency of the rural electrification program in Bangladesh while Ha et. al. (2010, 2013) measured and internationally compared the productive efficiency of the aviation sectors in east Asian countries.

In our analysis production set spans in a space of three inputs and one output, i.e, $M = 3$ and $N = 1$. Output is the total number of households serviced by SWPS, while three inputs are namely distribution tank capacity, solar panel peak kilo Watts, and the length of distribution pipe. Our DMU is at the ward level, which is the smallest jurisdictional unit in Nepal, that makes the various decisions concerning installation of the SWPS.cases of

3.2 Social and Technical Factors that Influences the Productive Efficiency of SWPS

We then analyze the obtained efficiency scores as described in the previous section using Tobit regression on social and technical factors.[9] Specifically, we estimate the following:

$$\tilde{y_i} = \beta' x_i + \varepsilon_i \tag{2}$$

$$\begin{cases} y_i = 1, & \tilde{y_i} \geq 1 \\ y_i = \tilde{y_i}, & \tilde{y_i} < 1, \end{cases}$$

where $\tilde{y_i}$ is the latent dependent variable, x_i is the vector of independent variables consisted of social and technical factors, and y_i is the observed efficiency scores obtained in the previous section.[10]

Social factors considered here are monthly user charges per participating household, proportion of government subsidy in the total installation cost, and the initial cost per household. Technical factors are the number of alternative water sources, accessibility to an expert advise during the planning process as a dummy, and the capacity of the collection tank as well as its cross term with distribution-tank capacity. The cross term of the tank capacities captures if marginal productivity of one tank is decreasing or increasing in capacity of another, and thus identifies if these two tanks are technical substitutes or complements.

4 Data and Results

4.1 Data

We conducted a field survey in 44 wards in 20 districts scattering across all seven regions in Nepal. The questionnaire contains 33 questions on the general information of the village and its SWPS, as well as those concerning the decision-making process and ex-post satisfaction of SWPS. Of these 44 cases of SWPS installation, six utilized external aid from international and/or non-governmental organizations. Excluding these six cases, we construct our data set containing 11 variables for 38 villages with SWPS installation, of which the summary is presented in Table 1.

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[9] DEA yields efficiency scores that are 100% for multiple DMUs, along with efficiency scores that are strictly below unity for inefficient ones. That is, observed efficiency scores are censored at one thus require utilization of Tobit regression.

[10] We assume normality for the distribution of error terms ε_i and estimate (2) via the maximum-likelihood method.

Table 1
Summary of variables.

	Average	Std. Dev.	Min.	Max.
Number of SWPS supplied households	46.24	17.07	20	95
Distribution tank capacity (cubic meters)	14.14	3.84	8.00	26.00
Solar panel capacity (peak kilo Watts)	1,693.16	602.75	420	3,040
Distribution pipe length (meters)	331.05	198.05	40	900
User charge per household (Rp. per month)	51.51	24.07	20	100
Total initial cost (Rp.)	2,232,595	679,780	1,456,664	4,640,000
Government subsidy (Rp.)	1,010,094	685,373	0	1,875,000
Total number of households	130.87	125.51	20	500
Number of alternative water sources	1.82	1.33	1	5
Access to technical consultancy (a dummy)	0.21	0.41	0	1
Collection tank capacity (cubic meters)	10.25	8.97	3.45	40.00

We use the first four variables, namely, the number of SWPS supplied households, distribution-tank capacity, solar-panel capacity, and distribution-pipe length for SWPS production technology identification via DEA. The other seven variables are used for the identification of the impact of social and technical factors on the SWPS efficiency in the second-stage Tobit regression.

4.2 DEA Scores of SWPS Productive Efficiency

Table 2
Measurement results of DEA efficiency scores.

	Average	Std. Dev.	Min.	Max.
Output-oriented VRS technical efficiency	0.621	0.239	0.242	1.000
CRS technical efficiency	0.574	0.235	0.241	1.000
Scale efficiency	0.922	0.092	0.665	1.000
for 11 increasing-return-to-scale DMUs	0.933	0.099	0.665	0.993
for 18 decreasing-return-to-scale DMUs	0.877	0.084	0.704	0.998

As described above we measure the production efficiency in terms of the actual number of SWPS-supplied households, relative to what is predicted by the sizes of physical inputs namely, the distribution-tank capacity, solar-panel capacity, and distribution-pipe length. Results of output-oriented DEA scores in Table 2 show that the average efficiency is 62.1% with standard deviation of 23.9% and minimum being 24.2%, while six out of 38 DMUs turned out to be 100% efficient. There are 30 DMUs that are scale inefficient, of which 11 exhibit increasing return to scale and 18 exhibit decreasing return to scale. Those DMUs exhibiting increasing return have relatively smaller production scale with the minimum scale efficiency as small as 0.665, while those exhibiting decreasing return have larger production scale with the minimum scale efficiency at 0.704. This suggests that the production exhibits rather strongly increasing return while the production scale is small, while it becomes decreasing-return-to-scale at the larger production scale, thus supporting our assumption of variable return to scale on the production technology of SWPS.

4.3 Impacts of Social and Technical Factors on the Productive Efficiency of SWPS

In this section we investigate the impacts of social and technical factors on productive efficiency of SWPS by applying the Tobit regression to the scores obtained in the previous section. We denote these factors as follows: monthly user charges per participating household as USERCHARGE; proportion of government subsidy in the total installation cost as SUBSIDYRATIO; the initial cost per household as UNITCOST; the number of water sources as NSOURCE; accessibility to an expert advise during the planning process as a CONSULTANCY dummy; the capacity of the collection tank as CTANKCAP; and the cross term of collection-tank and distribution-tank capacities as TANKINTER.

Table 3
Tobit regression results with output-oriented DEA efficiency as dependent variable.

	Coefficient	std. err.
USERCHARGE	-3.06E-03***	1.11E-03
SUBSIDYRATIO	-1.68E-01*	8.58E-02
UNITCOST	-4.47E-06***	1.19E-06
CONSULTANCY	-9.88E-02	1.47E-01
NSOURCE	1.37E-01***	4.36E-02
CTANKCAP	6.74E-02***	1.68E-02
TANKINTER	-3.57E-03***	9.05E-04
constant	6.53E-01***	1.00E-01

*** for p<0.01, ** for p<0.05, and * for p<0.1

As shown in Table 3, all social factors negatively influence the efficiency of SWPS, with USERCHARGE and UNITCOST being 1% significant and SUBSIDYRATIO at 10%. Significantly negative coefficient of USERCHARGE indicates that the imposition of user charges suppresses SWPS utilization relative to the efficient peers. Negativity of SUBSIDYRATIO tells that higher government subsidy ratio leads to lower efficiency, which further suggests the existence of distorted incentive of villagers to install SWPS that has excessive capacity, with their budget constraint softened with government subsidy.

Results of technical factors are quite informative as well. As NSOURCE, the number of available water sources, being 1% significant, geographical characteristics of the village are still a strong determinants of the resulting efficiency of SWPS. Capacity of a collection tank CTANKCAP has a positive coefficient, while its cross term with distribution tank TANKINTER is strictly negative, both at 1% significance. This implies that the marginal productivity of either tank is decreasing to the other, and thus that these two tanks are technically substitutes.

5 Conclusions

In the geographically-challenged mountainous hinterland in rural Nepal, often very basic social infrastructure such as electricity, water, and education to youths and children are insufficient. These problems are tangled each other, and it is hoped that the solar water pumping system (SWPS) will shed a light to this difficult issue. These rural villages, however, face tight financial and resource constraints, and therefore identification of efficient installation of SWPS is a keen policy agenda. By collecting original field data from 38 wards in all seven regions in the entire Nepal, this paper thus identified the technically efficient cases of SWPS, and then investigated relevant economic policy that will enhance the performance of SWPS.

We defined the productive efficiency of SWPS as the actual number of households that are served by SWPS relative to the number predicted by the sizes of inputs such as tank capacity, distribution pipe length, and solar panels' peak kilo watts, and measured it via data envelopment analysis (DEA). The obtained DEA efficiency scores are then attributed to the differences in social and technical factors. Our results show, on one hand that distribution and collection tanks are technically substitutive in SWPS, and on the other that abundant financial support from the government tend to result in the installation of inefficient systems, and that charging user fees significantly discourages villagers' participation to SWPS and hence undermines the potential benefit of SWPS.

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