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Keywords : renewable energy, solar pumps, feeder level solarization, energy water nexus, energy subsidies, irrigation water, electricity, groundwater depletion, Punjab

JEL Classification : Q1, Q20, Q25, Q42, Q58, O13, O38, P48

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Abstract

Diesel and electric pumps have dominated groundwater irrigation in Punjab since the advent of intensive agriculture in 1966. National policies offer a range of subsidies for solar pumps, but there is limited empirical evidence of their effectiveness in promoting adoption. To address this need, a discrete choice method is applied to estimate the level of financial incentives for solar pumps preferred by farmers. The results show that enhanced subsidies combined with energy buyback have a significant impact on adoption decisions. The impact of contextual factors on the acceptance of grid-connected solar pumps is also estimated. Additionally, willingness to pay estimates and economic evaluations are improved with the use of flexible mixed logit formulation. The findings confirm that low subsidy limits the diffusion of solar pumps in Punjab agriculture. Further, the results from the statistical models indicate high public acceptance of individual solar agriculture pumps. We suggest that solar subsidies combined with grid purchases of surplus solar electricity can both reduce emissions and reduce the over-use of ground water, by indirectly introducing a price of electricity for water pumping.

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Section 1: Introduction

India is set to achieve the target of 500 GW of renewable energy installed capacity well before 2030. However in the agriculture sector majority of the irrigation needs are currently still being met by electric or diesel-operated pumps. The Government uses several instruments to scale up solar irrigation (known as solarization) including 60 percent subsidy of the capital cost initially offered for off-grid solar pumps in areas without grid power, and later extended for

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grid-connected pumps, including feed-in-tariff rates for solar energy fed into the grid. More recently the policy offers 30 percent central financial assistance to developers for feeder-level solarization as a variant to the solarization of individual pumps policy. A solar agriculture feeder is essentially a 1-10 MW community scale solar PV power plant set up by a private developer which is interconnected to a 33/11 KV sub-station.

However, the upfront cost of solar pump is estimated to be ten times of a conventional pump and hence it requires capital subsidy and financing support including incentives to cover lifetime cost. In this context, knowledge of farmers' preferences and their willingness to pay for the attributes that characterize different monetary incentives for adoption of solar irrigation can provide information about possible directions governments can take or what aspects they should consider in the pursuit of transition to clean energy in India. Punjab is chosen for this analysis as the policy of free electricity for agriculture since 1997 reduces the running costs of conventional grid-connected pumps and makes it harder for solar pumps to compete. But subsidized or free power has also been held responsible for the rapid depletion and over-exploitation of groundwater resources (Baweja et al., 2017). Punjab is one of the nine Indian States witnessing a critical groundwater situation, both in terms of falling availability and deteriorating water quality. Free electricity to irrigate farmers' fields has prompted excessive pumping, besides indirectly causing soil degradation, soil nutrient imbalance, and increased carbon emissions. It is critical that solutions to unlock the invidious energy-water nexus and wean farmers away from electric/diesel pumps are urgently found.

This paper uses a discrete choice model to identify the incentives that are more likely to divert farmers from conventional pumps to solar irrigation, either at the individual level or at the community level. As the interest in renewable energy has increased, many studies have been conducted. In general, there are many papers that have studied public acceptance of renewable energy. Few studies have analyzed willingness to pay and preferences for incentives to switch to solar irrigation in India. Further, the number of such studies in the literature applying stated preference (SP) methods is very small. Therefore, this study aims to analyze the preferences for the financial incentive attributes for installing solar pumps in Punjab and to quantitatively predict public acceptance of solar irrigation through stated preference method.

The stated preference elicitation method is considered an appropriate method to elicit preferences, choice probabilities, and willingness to pay values (Sagebiel and Rommel, 2014). The method allows the estimation of marginal utilities and provides rich data for economic evaluation and decision-making. The choice model assumes that individuals' preferences are stated through their choices. Ideally, a choice experiment has more than two alternatives, a large number of attributes describing each alternative, and characteristics describing the socio-economic profile of each sampled respondent. Respondents are repeatedly asked to choose between alternatives that include these attributes with associated attribute levels. It is assumed that an individual would choose an alternative in a given choice set if the utility derived from that alternative is greater than from any other offered alternative. Discrete choice methods provide quantitative information on the strength of preferences and estimation of trade-offs respondents are willing to make between attributes as well as the probability of take-up of presented options. Estimation of tradeoffs allows policymakers to estimate how much of one attribute a consumer would be willing to give up for improvement in another.

The results of this stated preference study on preferences for incentives for solar pumps in India can be used as the basis for policy formulation, as public acceptance is crucial for the successful adoption of solar irrigation. The results of the study will also provide meaningful insights to enhance the public acceptance and improve the design of existing incentive schemes to increase the number of solar pumps in Punjab. The rest of the paper is organized as follows: Section 2 reviews the empirical evidence relating to financial incentives for adoption of renewable energy. Section 3 discusses the discrete choice methodology and describes the data applied in this study. Section 4 contains the empirical results. Section 5 discusses the results and policy implications, and Section 6 offers conclusions.

Section 2: Review of Literature

There is large academic literature establishing that subsidies are essential to accelerate solar deployment. Analyzing the performance of government subsidy polices, Shao and Fang (2021) found that government subsidies were conducive to the development of the PV industry in China. Yamaguchi et al. (2013) found that policy measures which reduce initial cost (e.g., subsidy programs) were more cost-effective for reducing CO2 emission than those reducing users' operating expenditure (e.g., feed-in tariff programs) in the residential sector of Japan. Scarpa and Willis (2010) suggested that the British government would have to give substantially larger grants than those currently available to significantly induce more households to install micro-generation technologies. Renewable energy adoption was significantly valued by households, but the value was not sufficiently large, for the vast majority of households, to cover the higher capital costs of micro-generation energy technologies. An empirical study of the German solar market by Lobel and Perakis (2011) demonstrated that it was better to provide strong subsidies in the early stages of the adoption process; raising early subsidies, and lowering future subsidies was a more efficient way to achieve the target. From the consumers' perspective, there is empirical evidence that financial cost of renewable energy is an important consideration. Rouvinen and Matero (2013) emphasized the role of the investment cost as the main attribute affecting Finnish home owners' choice of heating system, although nonfinancial attributes also had a considerable effect. Islam and Meade (2013) found that expected utility of households behaved intuitively to the cost of installation, energy cost saving, increase in emissions, and payback time in the diffusion of household photo-voltaic solar panels in Canada. Agarwal and Jain (2016) identified input costs, expected revenue from cultivation and cost of alternative irrigation solutions as the determinants of economic sustainability of solar irrigation in India.

The top ten global solar power producers in the world depend on instruments like feed-in tariff, net metering, quotas with green certificates, low-interest bank loans, renewable portfolio standards, investment tax credit, market premiums, and reverse auctions for the development of solar energy (Sahu 2015). In the case of China, fast growth of PV industry was due to the series of incentive policies provided by the government. Fifty percent subsidy was offered on grid-connected PV power generation systems and seventy percent subsidy on off-grid systems (Wang 2020). It is considered that lump-sum subsidy and concession projects would be the main channels for investment in large-scale PV power in China until the cost of PV systems becomes relatively steady (Zhang et al., 2012). In Australia, the water heater rebate program was successful in shifting the existing stock of electric heaters toward more climate-friendly versions (Wasi and Carson 2013). Evaluating the effectiveness of government incentives ranging from feed-in-tariffs to upfront rebates in Australia, Higgins et al. (2014) demonstrated that a feed-in tariff was more effective, particularly in the adoption of larger PV units. Chapman et al. (2016) observed that the introduction of over-generous feed-in tariff regimes, followed by rapid reduction and in some cases cessation of this support mechanism was a factor for the limited success of the residential solar policy initially in Australia.

In the case of solar-powered irrigation in developing countries, energy buyback option is an effective instrument to provide solar energy for irrigation needs and generate additional income for farmers (Shah 2018). However, households while exporting solar energy to the grid are attentive to the opportunity cost and do not treat solar generation as free. Solar energy farming with a power purchase agreement can create opportunity cost of inefficient or wasteful use of solar energy and reduce water pumping (Al-Saidi and Lahhman, 2019). However, an unintended consequence of paying high feed-in tariff is that a substitution effect may reduce consumption; however, an income effect at the same time may encourage more consumption. With the increase in solar production, the income effect is found to dominate the substitution effect. Thus, as feed-in tariffs rise, consumption may increase whilst sales may decrease. Mechanisms which separate income effect from realized electricity production and exports, such as lump sum installation subsidies are considered as an more efficient way to support solar energy (La Nauze 2016).

One common feature of the above studies is that government subsidies and feed-in–tariff rates equally play a key role in promoting public acceptance of renewable energy. Therefore the aim of the current study is to survey and study farmers' preferences for different incentives under two supporting schemes of capital subsidies and feed-in-tariff rates for grid connected solar pumps in India. The analysis relies upon choice experiment approach to evaluate and compare social preferences as discussed in detail below. In addition, for a developing country like India, energy storage remains too costly in integrating with solar pumps, although its price is declining. Therefore, the economics of storage battery was not included in this work.

Section 3: Discrete choice experiment approach

The nature of the discrete choice approach

Choice experiments have been considered an effective approach to examine factors important to the adoption of solar panels and sensitivity to policy incentives (e.g. Uz and Mamkhezri, 2024). Data from discrete choice experiments can be exploited for demand estimation and analysis, identifying consumer segments characterized by similar tastes and informing the design of products and services to match consumer preferences (Akcura and Weeks 2014). The discrete choice method is an efficient tool to determine stated preferences, derive WTP values, and bring to light trade-offs between attributes which are likely to be heterogeneous. The study applied a discrete choice experiment to identify and compare preferences for two alternatives – adoption of grid-connected individual solar pump at the farm by availing government subsidy or acceptance for solarized agriculture feeder installed by a developer at the distribution substation under central financial assistance. The empirical analysis in this paper is based on a large survey conducted with 859 farmers in the Indian State of Punjab in 2021-22 . A mixed logit model that allows for individual heterogeneity is used for estimation, and willingness-to-pay (WTP) values are calculated for the attributes of incentives for solar pumps. This paper contributes to the existing literature in three ways. First, we study farmers' stated preferences and WTP values for solar pumps with different levels of subsidy and feed-in-tariff rates, which have not been fully analyzed so far. Second, our study examines and compares stated preferences and public acceptance for individual pumps and solar feeders, particularly focusing on the grid-connected PV technology. Third, in addition to the stated preferences analysis, we further examine the potential for acceptance by carrying a cost benefit analysis for the key stakeholders – consumers, distribution utility and the state.

In order to identify relevant levels and attributes for the choice sets, a pilot survey was conducted in December 2019 with about 50-60 farmers of different districts in Punjab. Farmers were asked to share their concerns and problems with the policy of free electricity and existing supply schedules. Their opinions and feedback about moving away from the free regime and shifting to renewable energy sources and improving the design of existing schemes was taken. Secondly, extensive discussions were held with officials dealing with renewable energy policies in different State governments. Discussions revolved around the pros and cons of the existing schemes and suggestions for improving the affordability and acceptability of solar pumps. The full spectrum of issues from economic cost to the technical feasibility of solar pumps was discussed. Thirdly, opinions of experts in the electricity sector were taken about the proposed attributes and levels. A thorough analysis of the feedback gained during these discussions led to the selection of the final attributes and levels for this experiment.

Description of attributes and levels

The number of attributes in this discrete choice experiment was restricted to monetary incentives influencing adoption decisions. Two attributes were chosen based on literature review and feedback taken during the pilot study: (1) the level of subsidy on capital cost of solar pumps and (2) the feed-in-tariff rate.

Attribute 1: Subsidy on capital cost

The first attribute is subsidy on the cost of solar pump with five levels. Level one is nil subsidy reflecting the hypothetical alternative of solar agriculture feeder. Levels 2 and 3 offer 60 percent capital subsidy on investing in an solar pump of either 7.5 HP (horsepower) or 10 HP capacity to the farmer with the option to receive money from energy sales as income or offset in residential electricity bill. These two levels correspond to the subsidy offered by a Central Government scheme on solarization of grid-connected pumps. Levels 4 and 5 offer higher capital subsidy of 75 percent to the farmer, which reflects the higher subsidy policy of state governments, for example 75 percent subsidy in Rajasthan, 80 percent subsidy in Maharashtra, 95 percent in Gujarat etc. The higher subsidy of 75 percent on individual pumps with the option to receive energy sales as income or offset in residential is expected to significantly improve affordability and encourage faster adoption.

In order to prepare choice sets, the subsidy amount was calculated on the basis of the estimated cost of 7.5 HP with 10 KW solar photovoltaic panel at Rs. 410000 ($5148) prepared by Punjab Energy Development Agency (PEDA). The base cost of 7.5 HP pump was extrapolated to arrive at the estimated cost of Rs. 530000 ($6654) for 10 HP pump with 12.5 KW solar photovoltaic array as PEDA does not prepare estimates for 10 HP pump. The subsidized cost of 7.5 HP pump with 10 KW solar panel and that of 10 HP pump with 12.5 KW solar panel at 75 percent subsidy works out as Rs. 102500 ($1287) and Rs. 132500 ($1663). Likewise, with sixty percent subsidy, the subsidized cost of 7.5 HP pump and 10 HP pump with works out to be Rs. 164000 ($2059) and Rs. 212000 ($2661) respectively.

In addition to the subsidy, the attribute offered the choice of receiving money from surplus energy sales as income transfer or as an offset in the farmer's residential electricity bill. Compensation for excess electricity can be given in energy or monetary terms (Tongsopit et al., 2019). Traditionally, guaranteed buyback of surplus solar energy policy has given additional income to the 'prosumer'. The term prosumer is used to refer to energy consumers who also produce their own power from a range of different onsite generators (e.g. diesel generators, combined heat-and-power systems, wind turbines, and solar photovoltaic (PV) systems). Another type of transfer is the one-to-one offset policy which allows the offset of each unit produced by residential rooftop solar panel with consumption from the grid (Husain et al., 2021). This experiment applied the same analogy; electricity consumed for residential purposes was offered to be adjusted with the money from the sale of surplus energy fed into the grid. This choice was included in the choice sets as farmers get subsidized farm power but pay high rates for residential consumption. The aim was to examine whether the offset option would be preferred more than income transfer and thereby encourage adoption decisions.

Buyback rate/Feed-in-tariff

Grid-connected solar pumps come with the benefit of the buyback of surplus solar energy. It is estimated that on an average 7.5 HP water pump would generate 15025 kWh units of solar energy. After accounting for self-consumption of 7000 kWh units by the farmer, excess energy would be left for export to the grid at the feed-in tariff rate (Electricity Regulatory Commission, Petition 7 of 2020). Feed in tariff can encourage investment in individual solar pumps as it can help to recoup the initial investment made by the farmer. Hence, feed-in-tariff rate was included as the second attribute with three levels. The term buyback rate and feed-in-tariff rate would be used interchangeably for this analysis.

In the choice sets, level 1 was base level without the benefit of buyback of surplus solar energy. Level 2 presented farmers with the option of selling surplus solar energy at the government notified feed-in-tariff rate @ Rs. 2.6 /kWh ($0.032). Level 3 offered a higher buyback rate of Rs. 3.65/kWh ($0.045), similar to the policy of offering more attractive buyback rates by some state governments, for example, Rs. 3.44 per kWh offered in Rajasthan, Rs. 3.50/kWh in Gujarat etc.

Experimental design

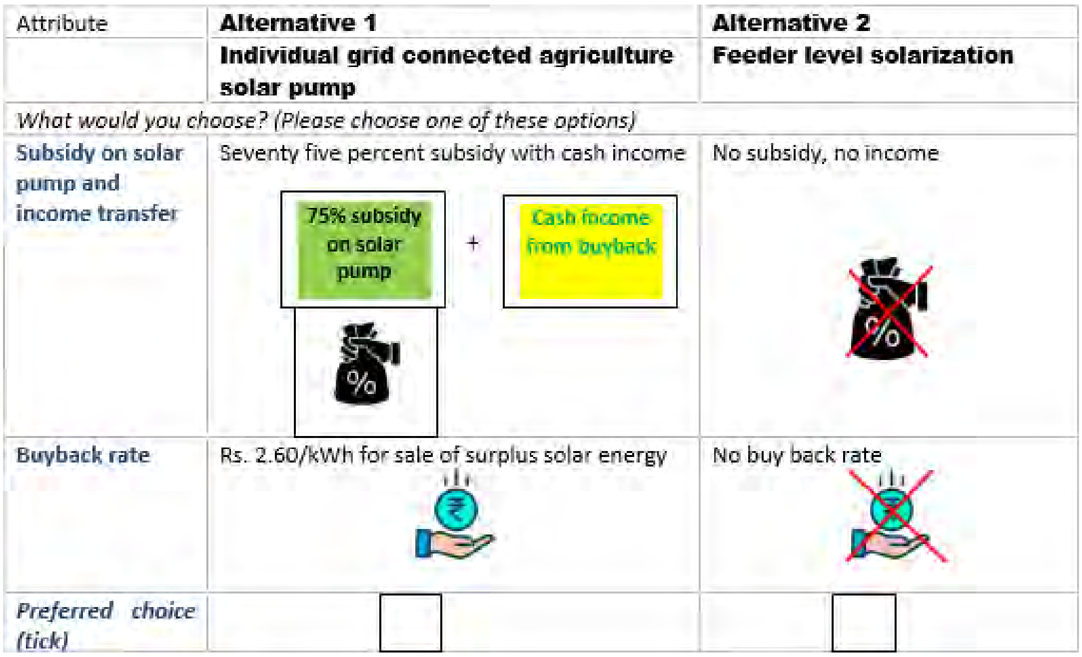
The choice experiment has two attributes, one with five levels and the second with three levels, hence there could be 5x3 = 15 choice profiles. The discrete choice sets were constructed using Ngene software. The Ngene-fractional factorial design gave eight choice sets with D-error of 0.8. In each choice set, the first alternative was to choose grid connected individual solar pump characterized by different levels of subsidy and feed-in-tariff rate. The second alternative was the option of solarized agriculture feeder which remained constant across all choice sets. All farmers were presented with all choice sets and each farmer made 16 decisions. This generated 13744 observations from in-person interviews with 859 respondents.

The attributes are summarized in Table 1. Figure 1 illustrates a choice card presented to the respondent. A questionnaire accompanying the choice sets included questions on socio-economic characteristics, demographics, and opinions about the prevailing subsidy regime and satisfaction level with the current supply schedules and quality of free electricity.

Table 1: Attributes and Levels

Attributes	Levels
1. Subsidy on capital cost of solar PV with income transfer	No subsidy 60 percent with income benefit 60 percent with offset in residential bill 75 percent with income benefit 75 percent with offset in residential bill
2. Buy back rate	No buy back rate Rs. 2.60/kWh Rs. 3.60/kWh

Figure 1: Example Choice set



Model Specification

The analysis of the choices made in a discrete choice experiment is based on random utility theory, developed by Mcfadden (1974). Specifically, it assumes that a decision maker, labeled n, facing a choice among J alternatives, obtains a certain level of utility (or profit) from each alternative. The utility that decision maker n obtains from alternative j is , *j = 1, ...J.* Decision maker will choose i if:

$$U_{ni} > U_{nj} \forall j \neq i \tag{1}$$

This utility is known to the decision maker but not to others. Since there are unobservable aspects of utility, $V_{nj} \neq U_{nj}$, Utility is decomposed as $U_{nj} = V_{nj} + \varepsilon_{nj}$, where ε_{nj} captures the factors that affect utility but are not included in V_{nj}.

The probability that n chooses alternative i is:

$$P_{ni} = Prob(\, U_{ni} > U_{nj}) \;\; \forall j \neq i$$

$$= \; Prob(V_{ni} + \varepsilon_{ni} > V_{nj} + \varepsilon_{nj}) \; \forall j \neq i$$

$$= (\varepsilon_{nj} - \varepsilon_{ni} < V_{ni} - V_{nj}) \; \forall j \neq i \quad (2)$$

This probability is a cumulative distribution, namely that probability of each random term $\varepsilon_{nj} - \varepsilon_{ni}$ is below the observed quantity $V_{ni} - V_{nj}$. Using the density f(ε_n), the cumulative probability can be re-written as:

$$P_{ni} = Prob(\varepsilon_{nj} - \varepsilon_{ni} < V_{ni} - V_{nj}) \forall j \neq i$$

$$= \int_{\mathcal{E}} (\varepsilon_{nj} - \varepsilon_{ni} < V_{ni} - V_{nj} \forall j \neq i) \, f\, (\varepsilon_n) \, d\epsilon_n \quad (3)$$

where $I(.)$ is the indicator function, equaling 1, when the expression in parentheses is true and 0 otherwise. This is a multidimensional integral over the density of the unobserved portion of utility, f(ε_n). Different discrete choice models are obtained from different specifications of this density, i.e., different assumptions about the distribution of the unobserved portion of utility. The logit is derived under the assumption that the unobserved portion of utility is distributed *iid* extreme value (Train 2009). Traditionally the choice is modeled using conditional logit in which choice is independent of irrelevant alternatives or error terms are assumed to be independently and identically distributed according to Gumbel distribution (Siyaranamual et al., 2020). This study applied conditional logit model and mixed logit model, which has a more flexible formulation.

The logit family of models is recognized as the essential toolkit for studying discrete choices (Hensher and Greene 2003). But there are practical problems with logit models. Firstly, logit can represent systematic taste variation which relates to observed characteristics of decision makers, but does not account for random taste variation or differences in tastes that cannot be linked to observed characteristics. Secondly, the logit model exhibits equal proportional substitution across alternatives. This is due to the assumption of independence from irrelevant alternatives or IIA. This implies that for any two alternatives *i* and *k*, the ratio of the logit probabilities does not depend on any alternatives other than *i* and *k*. IIA property has some practical uses as it allows examining choices among a subset of alternatives and not among all alternatives. If the researcher believes that the IIA property holds adequately well, then a model with the relevant alternatives could be estimated by excluding sampled individuals who used other alternatives from the analysis. This strategy would save the researcher considerable time and expense developing data on other alternatives, without hampering ability to examine factors related to the relevant alternatives. Thirdly, logit model can capture dynamics of repeated choice when unobserved factors are independent over time in repeated choice situations, but it cannot handle situations where unobserved factors are correlated over time (Train 2009). Therefore, to allow for general patterns of substitution, more flexible models are needed.

Mixed logit model is considered a highly flexible model that can approximate any random utility model (McFadden and Train, 2000). It obviates the three limitations of standard logit by allowing for random taste variation, unrestricted substitution patterns, and correlation in unobserved factors over time. Mixed logit models, also called random-parameters or error-components logit, are a generalization of standard logit that do not exhibit the restrictive "independence from irrelevant alternatives" property and explicitly account for correlations in unobserved utility over repeated choices by each customer (Revelt and Train 1998). Unlike probit, it is not restricted to normal distributions. Its derivation is straightforward, and simulation of its choice probabilities is computationally simple (Train 2009).

The derivation of mixed logit probability is based on random coefficients. The decision maker faces a choice among J alternatives. The utility of person n from alternative j is specified as:

$$U_{nj} = \beta_n' x_{nj} + \varepsilon_{nj} \tag{4}$$

where x_{nj} are observed variables that relate to the alternative and decision maker, β_n is a vector of coefficients of these variables for person *n* representing his tastes and ε_{nj} is a random term that is independent and identically distributed of extreme value. The coefficients vary over decision makers in the population with density $f(\beta)$. This density is a function of parameters θ that represent, for example, the mean and covariance of the β's in the population. This specification is the same as for standard logit except that β varies over decision makers rather than being fixed.

The usual form of the mixed logit probability is:

$$P_{ni} = \int \left(\frac{e^{\beta' x_{ni}}}{\sum_j e^{\beta' x_{nj}}} \right) f(\beta) d\beta \tag{5}$$

The mixed logit probability is a weighted average of the logit formula evaluated at different values of β, with the weights given by the density *f(β)*. The researcher specifies a distribution for the coefficients and estimates the parameters of the distribution. By specifying the explanatory variables and density appropriately, the researcher can represent any utility maximizing behaviour by a mixed logit model. In most applications, such as Revelt and Train

(1998) and Bolduc and Ben Akiva (1996), *f(β)* is specified to be normal or lognormal: $\beta \sim N(b, W)$ or $\ln \beta \sim N(b, W)$ with parameters b and W which are estimated (Train 2009).

Mixed logit model allows attribute coefficients to vary across respondents, accounting for preference heterogeneity and improving the realism of model assumptions. Secondly, mixed logit models adjust the standard errors of utility estimates to account for repeated choices by the same individual.

Estimation strategy

The farmers were faced with two alternatives in the experiment. The first alternative was to invest in individual grid-connected solar agriculture pump and get the benefit of buyback of surplus solar energy. The second alternative was to receive free solar electricity from a solarized agriculture feeder set up by a private developer and to not get the benefit of additional income from the sale of surplus solar energy. The deterministic part of the utility function is:

$$Adoption_{SIP} = \beta_0 + \beta_1\ x\ SixtyCas_1 + \beta_2\ x\ SixtyReb_2 + \beta_3 x\ SeventyCas_3 + \beta_4\ x\ SeventyReb_4 + \beta_5\ x\ Buybackrate_1 + \varepsilon \quad (6)$$

The four attribute levels of capital subsidy with the type of income transfer for alternative 1 were modelled as dummy variables – $SixtyCas_1$, $SixtyReb_2$, $SeventyCas_3$ *and* $SeventyReb_4$. Preferences were modeled relative to a base case (coded as 0) for dummy variables. where sixty percent subsidy on solar pump with energy sales as income benefit is denoted by $SixtyCas_1$ and β_1 is the associated sensitivity parameter; sixty percent subsidy on solar pump with energy sales as offset in residential electricity bill is denoted by $SixtyReb_2$ and the associated sensitivity parameter is β_2 ; seventy-five percent on solar pump with energy sales as income benefit is denoted by $SeventyCas_3$ and the associated sensitivity parameter is β_3 ; seventy-five percent subsidy on solar pump with energy sales as offset in residential electricity bill is denoted by $SeventyReb_4$ and the associated sensitivity parameter is β_4 ; the buyback rate for purchase of surplus solar energy is denoted by $Buyback\text{rate}_1$ and the associated sensitivity parameter is β_5. β_0 is a constant reflecting farmers' preference for solar pump.

The estimated parameters were interpreted as the marginal value of a movement from the base case to a defined level. The parameter for '$SixtyReb_2$' shows the value of moving from sixty percent capital subsidy with income benefit to sixty percent capital subsidy with offset in residential bill. Similarly, '$SeventyCas_3$' shows the value of moving to seventy-five percent capital subsidy with income benefit, and '$SeventyReb_4$' shows the value of moving to seventy-five percent capital subsidy with offset in residential bill. Buyback rate is treated as a continuous variable in the estimation. Feeder-level solarization corresponding to no capital subsidy on solar pump is given a dummy value of 1 for second alternative and 0 otherwise.

The mixed logit model was fitted on the choice data treating the coefficient for the rate as fixed and the subsidy with income transfer coefficients as normally distributed. A main effects model was used without any interaction effects. Each farmer was presented with eight choice sets and there were two alternatives in each choice set– first alternative for individual solar pump and the second alternative for feeder-level solarization. The survey produced 13744 observations in total.

Section 4: Empirical results

Table 2 presents the main results and sheds light on the average valuation of the various attributes. The choice was modelled using mixed logit or random parameters logit, random effects probit and conditional logit models. More specifically, the IIA assumption was relaxed by using mixed logit and random effects probit. All estimated parameters are highly significant and in the expected direction in the three models. Results of mixed logit and conditional logit are presented in Table 2 below. The coefficients and WTP values with random effects probit model are reported in Table 9 in the Appendix. Farmers have strong preferences for seventy-five percent subsidy as compared to sixty percent subsidy on the cost of solar pump. There is evidence of a preference for income from energy sales as compared to receiving an offset in the residential electricity bill. While the higher subsidy is important to all farmers, there is significant increase in utility for higher component of subsidy combined with option of income from energy sales. The positive value of the coefficient for buyback rate indicates preference for installing individual grid connected agriculture solar pump among farmers.

Table 2: Estimation Results

Attribute	Coefficient	Std. Error	Coefficient	Std. Error
	Mixed logit		Conditional logit	
Mean				
Sixty_Reb	-2.3148***	0.199	-1.7529***	0.093
Seventy_Cas	3.4559***	0.250	2.9486***	0.103
Seventy_Reb	0.1571***	0.079	0.1868***	0.070
Buy back rate	0.8953***	0.065	0.8208***	0.061
const	-3.2122***	0.212	-2.9777***	0.200
Log likelihood	*-3284.60*		*-.3304.36*	
Pseudo R^2	*0.3070*		*0.3063*	
N	*13744*		*13744*	
SD				
Sixty_Reb	1.2992***	0.227		
Seventy_Cas	1.1648***	0.294		
Seventy_Reb	0.8556***	0.141		
AIC	6585.217		6618.721	
BIC	6645.443		6656.363	

****$p < .05$*

On an average, higher buy back rate, higher capital subsidy of seventy-five percent on the cost of solar pump and income transfer of energy sales is likely to increase the probability of choosing individual grid-connected solar pump among farmers. Further, there is significant preference heterogeneity for the attributes.

Assuming a normal distribution for random parameters, mixed logit model provides output that can be used to calculate the proportion of respondents for whom an incentive attribute has a positive or negative effect on preferences. From the magnitude of the standard deviations relative to the mean coefficients, 3.6 percent prefer sixty percent subsidy with offset in residential electricity bill, 0.15 percent farmers were not likely to prefer seventy-five percent subsidy with income benefit and 42 percent farmers were not likely to prefer seventy-five percent subsidy with offset in residential electricity bill. These figures are given by 100 x (b_k/s_k), where Φ is the cumulative standard normal distribution and b_k and s_k are the mean and standard deviation, respectively of the *kth* coefficient (Hole 2007).

Willingness to pay/willingness to accept for an attribute is the ratio between the attribute's coefficient and the price coefficient, which is estimated as:

$$illingness\ to\ pay = \frac{\beta_{Attribute}}{\beta_{Rate}} \quad (7)$$

Willingness to pay/willingness to accept estimates and 95% confidence intervals are presented in Table 3 below. WTP/WTA values from mixed logit are estimated within preference space. The results indicate that WTP/WTA is Rs. 3.8($0.04)/kWh for seventy-five percent subsidy with income benefit and Rs. 0.17($0.002)/kWh for seventy-five percent subsidy with offset in residential bill. On the other hand, the farmer may need to be compensated for accepting reduced subsidy of sixty percent. The WTP/WTA values estimated with random effects probit model are reported in Table 9 in the Appendix.

Table 3: Willingness to pay/willingness to accept

Attribute	WTP Mixed logit	Std. Err.	WTP Conditional logit	Std. Err.
Sixty_Reb	-2.585***	0.278	-2.135***	0.189
Seventy_Cas	3.859***	0.377	3.592***	0.282
Seventy_Reb	0.1755***	0.089	0.227***	0.087

****$p < 0.05$*

There is some debate regarding the appropriateness of calculating WTP estimates in preference space. Of particular concern is the assumption regarding the distribution of the price variable. A fixed price coefficient assumed to estimate the distribution of consumers' willingness to pay for the attributes, implies that the standard deviation of unobserved utility or scale parameter is the same for all observations. In some situations, ignoring the variation in estimation can lead to erroneous interpretation. Train and Weeks (2005) suggest a way to circumvent this problem by estimating the mixed logit model in WTP space rather than in preference space (Hole 2016). The estimation of the mixed logit model in WTP space is presented in Table 12 in the Appendix. While alternative techniques have been suggested, however no gold standard has been accepted so far (Ryan et al., 2012). The models in preference space continue to be considered to fit the data better.

The discrete choice experiment results have been used to show how the probability changes for an alternative, in other words, how the probabilities vary in response to changes in the levels of attributes (Hole 2007). Table 4 shows the change in probability of choosing solar agriculture pump with change in subsidy under mixed logit model. The results of predicted probabilities from conditional logit and random effects probit models are presented in Table 10 in the Appendix.

Table 4: Predicted probabilities

Attribute	Mean	Std. Dev
Mixed logit		
Sixty_Reb	-0.288***	0.11
Seventy_Cas	0.425***	0.15
Seventy_Reb	0.025***	0.02

****p < .05*

Potential uptake of choosing solar pump is simulated by comparing the uptake of solar agriculture pump with seventy-five percent subsidy with respect to the baseline level of sixty percent subsidy with offset in residential bill. The results of the selected simulations are shown in Table 5. There is higher probability of uptake for capital subsidy with income benefit of energy sales.

Table 5: Change in probability

Attribute	Mean	Std. Err.	Mean	Std. Err.
	Mixed logit		Conditional logit	
Seventy_Cas	0.993***	0.001	0.982***	0.002
Seventy_Reb	0.844***	0.029	0.748***	0.020

****p < .05*

Table 11 in the Appendix reports the marginal effects computed at means with random effects probit and conditional logit models. Marginal effects represent the variation in choice with a change in the level of the capital subsidy and buyback option.

Comparison of coefficients between the regions: There are considerable spatial differences in the strength of farmers' preferences for various attributes of solar pumps across three different regions of Punjab. The segmentation analysis was conducted for the three regions of Punjab– Malwa, Majha and Doaba, broadly carved by three of the rivers, with their own distinct social, economic and political identities. The word 'Punjab' literally translates to 'Panj' (five) and 'Aab' (sources of water), and was known as the 'land of five rivers' — the Sutlej, Beas, Ravi, Chenab and Jhelum. Going from west to east, the Majha region falls between the Ravi and the Beas, then begins Doaba, the land between two rivers (*do aab*), which starts from the Beas and goes on till the Sutlej. Beyond the Sutlej lies the Malwa region.

In terms of geographical and political characteristics, Malwa is the largest region of Punjab. It is also known as the 'zamindari' belt as it is home to rich farmers and landholders, but is infamous for farmer suicides. This belt compared to Majha and Doab belts has a less educated population and huge number of small and marginal farmers. It has been associated with farmer activism and protests since the last two decades. Majha is known as the religious belt for the various sacred temples in the region. The average landholding in Majha is small; over 58 per cent farmers own less than five acres of land. Doaba is the smallest region in Punjab politically, which is flanked by the Sutlej and Beas rivers. Doaba is known to have the most fertile land as the irrigation system reaped the benefits of the Green Revolution. Though it has a high share of small and marginal farmers, the share of educated people is reportedly also higher in this region compared to Majha and Malwa. Doaba is also known as the 'Non Resident Indian' belt of Punjab. The trend of migrating to developed countries started from Doaba, which has sharpened in the last two decades due to slow growth of Punjab's economy and persistence of high unemployment rates.

The choice data for this paper was analyzed for exploring variations across farmers in these three regions. Doaba region farmers are the most inclined to adopt solar irrigation pumps. Table 6 shows that farmers in the Malwa, Majha and Doaba regions are statistically more likely to support seventy-five percent capital subsidy on solar irrigation pumps with income benefit of energy sales. Majha region farmers do not show any preference for the option of offset in residential electricity bill. Farmers in the three regions prefer the attribute of buyback rate, although Majha region farmers are more likely to choose irrigation pumps with the option of buyback of surplus solar energy. This finding implies that farmers' preferences across agro-ecological regions cannot be pooled together. However, it can be inferred that farmers across all regions are equally interested in solar pumps as an alternative to subsidized electric pumps.

Table 6: Estimation results – by region

Attribute	Malwa	Majha	Doaba
Sixty_Reb			
Mixed logit	-1.932*** (0.219)	-3.435*** (0.620)	-2.761*** (0.924)
Conditional logit	-1.615*** (0.11)	-2.111*** (0.205)	-1.992*** (0.291)
Seventy_Cas			
Mixed logit	3.281*** (0.256)	3.847*** (0.723)	4.690*** (0.818)
Conditional logit	2.829*** (0.123)	3.512*** (0.316)	3.149*** (0.259)
Seventy_Reb			
Mixed logit	0.235*** (0.108	-.3625*** (0.159)	0.498*** (0.189)
Conditional logit	0.285*** (0.088)	-0.357 (0.157)	0.5059*** (0.184)
Buy back rate			
Mixed logit	0.916*** (0.082)	1.057*** (0.146)	0.680*** (0.170)
Conditional logit	0.815*** (0.075)	1.002*** (0.141)	0.6354*** (0.163)
N	8912	2752	2080

****p < .05*

Interaction terms: Respondents characteristics are important in forming preferences. The data is examined for association between the choices made by farmers and their socio-economic and demographic characteristics. The heterogeneity in preferences by education level, land size, tube well ownership and load capacity of farmers is estimated using conditional logit and random effects probit models. The results are presented in Table 8 in the Appendix. Results show that education is an important explanatory variable. School educated (matriculate) and graduate farmers are significantly more likely to agree for buyback of surplus solar power. There is no preference for the offset option among matriculates and graduates.

Land ownership has an influence on preferences. Semi-medium, medium, and large farmers are significantly more likely to prefer buyback of surplus solar power. Similarly multiple tube well owners significantly prefer buyback of surplus solar power, with increases in tube well ownership resulting in more favorable inclinations. Small and marginal farmers show positive preferences for buyback option, although the coefficients are not significant. Again, there is no preference for the offset option; negative preferences are significant for small farmers, large farmers, single tube well owners and multiple tube well owners. Larger farmers are relatively more likely to adopt solar irrigation pumps with higher capital subsidy, although the coefficients are not significant. However, semi-medium farmers do not significantly prefer capital subsidy on solar pump.

Farmers with pumps of different capacities have significant and positive preferences for buyback of surplus solar power. Similarly, they have significantly negative preferences for seventy-five percent subsidy with offset option. Again, farmers with medium and high pump loads do not significantly prefer sixty percent capital subsidy with offset option. Farmers with low pump load are significantly not likely to prefer seventy-five percent subsidy with income benefit of energy sales, in contrast to farmers with high pump load who show positive but not significant preferences.

Section 5: Discussion

The econometric analysis in this paper suggests that higher subsidy on capital cost is a highly significant predictor of adoption of individual solar pumps. The results show that seventy-five percent capital subsidy is acceptable to 91 percent of the farmers at the buyback rate of Rs. 2.6/kWh. On the other hand, sixty percent subsidy is preferred by only 35 percent of the farmers. In terms of the hypothetical alternative of receiving the benefit from the sale of surplus solar energy as an offset in residential bill with seventy-five percent subsidy, 25 percent of the farmers show preferences at lower buyback rate of Rs. 2.6/kWh and 62 percent show preferences at the higher buyback rate of Rs. 3.6/kWh. The preferences for the offset option are considerably lower at 7 percent and 13 percent at sixty percent subsidy for the two buyback rates respectively.

The findings indicate that the feed-in tariff can be the main instrument to promote the adoption of decentralized solar generation in agriculture and prevent over-exploitation of groundwater. Applying targeted interventions informed by preferences could bring about the desired change. Introducing a buy-back rate differentiated by season and location could conserve groundwater. Pegging the buyback rate at the correct price would depend on the marginal profitability of water use. A very low buyback rate would disincentivize farmers from changing pumping behaviour while a very high buyback rate is likely to create perverse incentives (Franklin 2015).

There are significant differences in the WTP/WTA for different attribute levels. Farmers are willing to pay more for higher subsidy and would need to be compensated to install individual solar pumps at lower subsidy. Solar feeders are preferred at lower subsidy levels. The effect of the buyback rate is positive and significant on adoption indicating that its presence is a driving factor. The spatial picture confirms evidence of positive effect of higher capital subsidy and buyback rate. Educated farmers are more likely to adopt solar agriculture pumps. Farmers with medium landholdings, large landholdings and multiple tube wells prefer the buyback option.

The analysis reveals possibility of a nonlinear relationship between solar uptake and income; as income increases, it is possible that solar pump uptake might not increase in a straight-line relationship, it could be curved. Higher-income farmers or those with higher accumulated assets may have reduced motivation for investment in solar pump due to lower stress of additional expenditure on diesel. More affluent farmers may be less worried about high diesel prices (Best and Chareunsy, 2022). Secondly, the positive relationship between solar uptake and income may be restricted to the low end of the income distribution. After a peak in the middle of the income distribution, a negative relationship between income and solar panel uptake is possible for high-income households.

Overall, to the extent solar pumps wean farmers away from electric pumps, there would be a reduced burden of electricity subsidies and greenhouse emissions. While a thorough examination is beyond the scope of this study, preliminary cost-benefit analysis shows that incentivizing solar pump adoption can be financed from switching the delivery of free electricity on electric pump to offering higher subsidy on solar pump. The analysis is carried out for 7.5 HP pump with 10 KW solar PV panels in Table 7.

Table 7: Financing higher solar pump subsidies out of electricity subsidy savings (per farmer)

	For the Farmer		
1	Capital cost of 7.5 HP 10 KW solar pump	$	5166.07
2	Farmers contribution - 25% of cost	$	1291.51
3	Total generation	kWh	15025
4	Self-consumption	kWh	7000
5	Surplus generation	kWh	8025
6	Buyback rate for surplus energy	$/kWh	0.032
7	Agriculture tariff on electric pumps	$/kWh	0.071
8	Local purchase of solar energy by utility	$/kWh	0.012
9	Gain for the farmers from surplus generation {2.6*8025}	$	261.99
10	Additional gain due to efficient pump (20% saving in energy consumption) - {20% of 7000}	kWh	1400
11	Additional income for farmers due to efficient pump {2.6*1400}	$	45.70
	Total gain for farmers {9+11}	$	307.69
	For the Utility		
12	Utility saving in electricity subsidy {5.66*7000}	$	497.48
13	Additional gain from surplus energy purchased locally @ Rs. 1/kWh {1*8025}	$	100.76
14	Additional gain from surplus power purchased due to efficient motor {1*1400}	$	17.57
	Total gain for utility {12+13+14}	$	615.83
	For the Govt		
15	Additional burden of giving 75% subsidy	$	772.22
	For the environment		
15	Total solar generation	MWh	15.025
17	Weighted average carbon emission factor	tonnes/MWh	0.82
18	Reduced carbon dioxide emissions	tonnes	12.3205

($-Rs.79.6) Authors calculations based on Tariff order, Punjab State Electricity Regulatory Commission (2020)

The above analysis shows that installation of 10KW individual solar pump could potentially give net gain of $616 to the utility and additional farm income of $308 to the farmer. Further, given the current electricity supply schedule for paddy and non-paddy season and assuming that 7.5 HP pump can cater to five acres, solarization of grid connected pump could potentially lead to water savings of approximately 58m^3 per farmer as more energy is exported back into the system, thereby putting a check on high extraction of groundwater. Determining the net cost-benefit to the economy of say, substituting 25000 grid-connected solar pumps with electric pumps in Punjab, we find that the additional cost of subsidizing solar pumps would be $42.5 million and net benefit of reduced carbon emissions would be 308000 ton/MWh. On the other hand, setting up solar feeders involves expenses on design, development, commissioning, operation, management, and maintenance. It is estimated that the cost of setting up 1MW solar plant in India is $0.608 million, which on average can cater to 133 irrigation pumps of 10 KW capacity. In case solar feeders have to be set up to cater to equal number of 25000 pumps, the approximate investment cost would be around $32.8 million. In addition under feeder-level solarization, disbursing an incentive to reward lower consumption than the optimal benchmark level would be an additional cost. Further, solar feeders come with its own set of challenges such as acquiring costly agricultural land, trade-off between developer's interest in earning attractive return on investment and farmer's interest in keeping tariff at affordable level, issue of metering and ensuring timely payment to developers, cases of poor response of developers to government tenders, dependency of the farmer on the grid etc. On the other hand, opting for grid-connected individual solar pump would give round the clock supply with some degree of control and ensure steady income to the farmer with judicious and optimal use of water.

The major finding from this work is that higher capital subsidies are required to effectively promote adoption of solarized water pumps. Under the net metering scenario, solar pumps can effectively address concerns about groundwater sustainability. An evaluation of integration of PV solar installations connected to the grid in the agriculture sector recommends net-metering and/or self-consumption schemes. Grid-connected solar pumps can reduce dependence on fossil fuels, increase integration of solar solutions and preserve the aquifer (Rubio-Aliaga et al., 2019).

Understanding the practical considerations, the cost benefit analysis supports financing the higher subsidy component from the free electricity subsidy. In the beginning, solar pumps can be offered to farmers awaiting the release of new electric connections in Punjab, though the paper establishes acceptance by majority of all farmers. Solar pump can replace conventional diesel or electric pump due to advantages in improving energy efficiency (Sreewirote et al., 2017). Studies carried out to analyze life cycle cost show that the cost of solar photovoltaic pump is much cheaper compared to diesel pumps (Table 13 in Appendix). The fuel and replacement cost for solar pumps is negligible which reduces their life cycle cost (Dadhich and Shrivastava 2017). Discounted benefits of solar pumps exceed their present value of costs and investment.

The results indicate that grid-connected solar pump can become a viable green alternative to electric pumps, provided a good financing model and institutional support are made available.

Deployment of solar pumps increases agricultural productivity and farmers' income (Beaton 2019), but the negative impact on water extraction can be mitigated by using water more efficiently. The ability to reduce excessive groundwater region varies with the region. They are a win-win solution where farmers use surface water. They are economically feasible in areas with adequate solar radiation, crops with low-water demand and high economic value, small plots, and irrigation techniques with higher efficiency (Noumon, 2008).

Section 6: Conclusions

Solar power offers the potential to meet a substantial share of the requirement of electricity in agriculture, but the current level of adoption by farmers is low in India. Despite the potential of solar energy generation in one of the major agricultural state of India, only a small proportion of the farmers use solar agriculture pumps in Punjab. This paper applied choice modeling to understand the acceptance of grid-connected solar pumps and farmers' willingness to pay for solar energy. Choice data was collected from 859 farmers in Punjab in 2021-22 and mixed logit and conditional logit models were used to estimate farmers' preferences for financial incentives covering capital subsidy and buyback options on solar pumps.

The results show that the capital subsidy on the solar pump is positively associated with intention of farmers' to substitute electric pumps powered by free electricity by solar pumps. The willingness to pay for solar pumps increases with higher capital subsidies. A seventy-five percent capital subsidy on solar pump is associated with 93 percent uptake, while sixty percent subsidy has a 35 percent uptake. There are heterogeneous preferences for different types of financial incentives. The study establishes that the absolute subsidy is not the only factor but a lot depends on the how the financial incentive schemes are designed. The findings in this paper confirm that solar pumps need subsidies and preferably easy access to credit, particularly credit-linked capital subsidy as most farmers lack financial resources.

Further, the results demonstrate that the socioeconomic characteristics of the farmers play significant role in influencing uptake. More educated, medium, and large farmers and multiple tube well owners are more likely to accept grid-connected solar pumps. Inadequate information about schemes and lack of institutional support are observed as reasons for the stated unwillingness to accept solar pump. Therefore, providing awareness about installing and using solar pumps is likely to enhance farmer acceptance of solar PV technology in agriculture.

The high preference for the buyback of surplus solar energy among various socioeconomic groups and sub-regional divisions has strategic implications. First farmers do express, on average a preference for solar buyback, thus indirectly putting a price on their own electricity consumption. Secondly, the combination of subsidy and buyback drives farmers to choose individual pumps more often over solar feeders. Feeder-level solarization is considered the second-best option. From the users' perspective, individual pumps are more convenient. Thirdly, the energy buyback option can incentivize judicious water use because using electricity for water pumping reduces export to the grid.

These findings can help to strategize balanced mix of individual solar pumps and solar feeders for incentivizing prosumers in selling solar energy and consumers in managing their demand. An increase in demand and technological advancements in solar energy will present opportunities for individual and community solar penetration. Future work could determine different incentives to be offered and buyback prices differentiated by geographic, seasonal, farm, and household characteristics.

Although the study adds to the understanding of farmers' preferences to install solar agriculture pumps and provides policy measures for deploying solar pumps, it has several limitations. As the study is based on stated preferences, there is the possibility of hypothetical bias. Moreover, it is important to note that the stated farmers' willingness to pay is not an actual payment for the solar pump. Stated preference methods have been critiqued because they may not predict real behaviour and choices. There are concerns about the external validity of the method. The context and individual experience have impact on the responses. As the questionnaire presents brief descriptions of the attributes, there can be some variation in how the attributes and levels are interpreted by different respondents. Finally, when the attributes are currently not available (such as potential policy interventions), it is difficult to assess the extent to which respondents would be able to relate to or appreciate the hypothetical scenarios.

Future research can extend the experiment to explore locally appropriate service delivery models and other incentive instruments for solar energy penetration. In the free-riding context, a possible extension could be to study the effect of a tax to prevent over-extraction of groundwater and a reward for reducing consumption. Future work could include supplementary questions designed to identify the confidence of the respondents about their choices and whether they would hypothetically purchase the pump chosen in the choice experiment. Studying the impact of adoption by an individual farmer on other farmers' adoption decisions can be extended in future research.

The results of this study provide essential information for developing effective solar energy promotion policies. Given the extent of network externalities in the electricity sector, it is crucial that the adoption process of solar pumps accelerates, and that the government subsidizes solar technology. Promoting solar pumps will make them cost competitive with traditional sources of power generation and foster technology improvements, thereby making them economically self-sustainable in the long run. These findings are not only relevant for facilitating the adoption of solar pumps but can also effectively encourage the adoption of other renewable energies.

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Appendix

Table 8: Interaction terms

Sixty_Reb	Coef.	Std. Err.	Coef.	Std. Err.
	Random Effects Probit		Conditional Logit	
Low load	-.1796	.1561	-.3375	.2887
Medium load	-.3097*	.1667	-.6102**	.3069
High load	-.6918**	.2756	-1.3831**	.5385
Seventy_Cas				
Low load	-.3211**	.1529	-.5271*	.2816
Medium load	-.1286	.1759	-.0362	.3431
High load	-.0241	.2876	.1792	.5990
Seventy_Reb				
Low load	-.5177**	.1275	-.8240**	.2086
Medium load	-.7741**	.1382	-1.315**	.2260
High load	-.9469**	.2113	-1.5892**	.3448
Rate				
Low load	.0867**	.0318	.1454**	.0482
Medium load	.1938**	.0343	.2889**	.0519
High load	.1429**	.0516	.2636**	.0769
Sixty_Reb				
Single well	-.0946	.1709	-.2315	.3151
Multiple well	-.2262	.1661	-.4520	.3047
Seventy_Cas				
Single well	-.1252	.1657	-.2416	.3055
Multiple well	-.0775	.1658	-.0664	.3119
Seventy_Reb				
Single well	-.3108**	.1394	-.5591**	.2274
Multiple well	-.6471**	.1364	-1.1088**	.2226
Rate				
Single well	.0334	.0346	.0682	.0521
Multiple well	.1326**	.0338	.2045**	.0508
Sixty_Reb				
Marginal	-.2263	.2272	-.4440	.4130
Small	-.3859*	.2111	-.7844**	.3935
Semi medium	-.1374	.1990	-.2955	.3592
Medium	-.1147	.2031	-.2790	.3670
Large	-.2866	.2374	-.5639	.4256
Seventy_Cas				
Marginal	-.2063	.2339	-.2705	.4378

Small	-.1911	.2098	-.2724	.3884
Semi medium	-.4049*	.2041	-.6404*	.3772
Medium	-.0105	.2162	.0818	.4099
Large	.0926	.2785	.4594	.5819
Seventy_Reb				
Marginal	-.0040	.1898	-.0051	.3073
Small	-.0188	.1717	-.0125	.2785
Semi medium	-.1851	.1682	-.3785	.2727
Medium	-.1575	.1716	-.3830	.2783
Large	-.3958*	.2012	-.7014*	.3263
Rate				
Marginal	.1008**	.0468	.1131	.0696
Small	.0423	.0424	.0499	.0633
Semi medium	.0976**	.0414	.1316**	.0618
Medium	.0905**	.0423	.1153*	.0630
Large	.1636**	.0495	.2204**	.0736
Sixty_Reb				
Upto Matriculation	-.0382	.1710	-.0227	.3240
Upto Graduation	-.0942	.1754	-.0962	.3316
Above Graduation	.0757	.2895	.2002	.5273
Seventy_Cas				
Upto Matriculation	-.2530	.1670	-.3893	.3099
Upto Graduation	-.1725	.1734	-.2238	.3242
Above Graduation	.6510	.4331	1.667	1.068
Seventy_Reb				
Upto Matriculation	-.2267*	.1375	-.4108*	.2228
Upto Graduation	-.2505*	.1412	-.4729**	.2289
Above Graduation	-.1559	.2429	-.4718	.3940
Rate				
Upto Matriculation	.0938**	.0340	.1224**	.0508
Upto Graduation	.1136**	.0349	.1433**	.0521
Above Graduation	.0912	.0600	.0954	.0888

** p < .10, **p < 0.05*

Table 9: Estimated parameters and WTP - Random Effects Probit

choice	Coef.	Std. Err.	WTP	Std. Err.
1.Sixty_Reb	-1.0070***	.0513	-2.1753***	.1950
1.Seventy_Cas	1.6965***	.0541	3.6649***	.2965
1.Seventy_Reb	.1106***	.0436	.2390***	.0960
Rate	.4629***	.0356		
const	-1.7838***	.1162		
_cons	.08399***	.0151		
/lnsig2u	-25.59121	5877.		
sigma_u	2.77e-06	.0081		
rho	7.69e-12	4.52e-08		

Table 10: Predicted Probabilities - Random Effects Probit and Conditional Logit

Random effects probit			Conditional logit	
	Margin	Std. Err.	Margin	Std. Err.
Sixty_Reb	.2146***	.012	.2007***	.011
Seventy_Cas	.9100***	.007	.9061***	.007
Seventy_Reb	.5314***	.013	.5159***	.012

Table 11: Marginal Effect - Random Effects Probit and Conditional Logit

Attribute	Mean Random effects probit	Std. Err.	Mean Conditional logit	Std. Err.
Sixty_Reb	-0.3370***	.0165	-0.357***	0.018
Seventy_Cas	0.5678***	.0163	0.60***	0.019
Seventy_Reb	0.0370***	.0145	0.038***	0.014
Rate	0.1549***	.0117	0.167***	0.012

Table 12: WTP Space Results

choice	Coefficient	Std. err.
Mean		
Sixty_Reb	-40.132***	9.741
Seventy_Cas	64.178***	15.17
Seventy_Reb	.5962	.6426
mRate	-2.591***	.1704
SD		
Sixty_Reb	-10.773***	3.622
Seventy_Cas	20.681***	5.175
Seventy_Reb	4.600***	1.225
mRate	1.1750***	.1612

Table 13: Net Present Value and Benefit Cost Ratio

	Grid connected solar pump
Net Present Value of Inflows ($)	16676
Net Present Value of Outflows ($)	11409
Benefit Cost Ratio	1.46

Table 14: Life Cycle Cost Analysis comparison of solar and diesel pump

Cost	7.5 HP Solar PV	7.5 HP Diesel engine
Capital cost ($)	5148.1	376.6
Maintenance cost ($)	852.2	941.7
Fuel cost ($)*	-	41430.9
Replacement cost ($)	-	376.6
Total outflows ($)	6000.4	43126.1
Present value of outflow ($)	5454.9	39205.5
Salvage value ($)	617.7	75.3
Present value of inflow ($)	561.6	68.4
Life cycle Cost ($)	4893.3	39137.05

Authors calculations based on Dadhich & Shrivastava (2017)

**Annual fuel cost of diesel pump: Specific fuel consumption x capacity x Fuel price x 6 hours*