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Who is willing to pay for solar lamps in rural India? A longitudinal study

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ABSTRACT

Solar lamps are a quick, affordable, and effective way to provide basic lighting for households in rural areas of developing countries. However, implementers and researchers argue that the market for solar products is hampered by a lack of awareness and willingness to pay (WTP) for solar technology. In this paper, we investigate awareness of solar products, household motivation to adopt solar technology, household perception of solar lamps when compared to kerosene-based lighting devices, and lastly, the availability of electricity after dark. We analyzed a repeated-measures (longitudinal) data of 1159 rural households in energy-poor villages in the states of Bihar, Jharkhand, and Uttar Pradesh, India. Longitudinal logistic regression analyses were performed to study how various factors influence users WTP for solar lamps at Indian market price (~8.61 US$) over time. We find that households awareness of various solar products and their motivation to adopt solar technology has increased over time but there is much room to grow awareness in Bihar, Jharkhand and Uttar Pradesh, especially for solar home systems and solar water pumps. Our model predicted that the households WTP for solar lamps at the market price increased with high income but it is significantly moderated by their level of awareness of solar products and their motivation to adopt solar technology. These findings suggest that increasing awareness of solar products through various dissemination programs leading to significant interest in solar products among people which in turn may enhance their WTP for solar products.

1. Introduction

The number of households with access to electricity is rapidly changing in rural India. In April 2018, the Government of India (GOI) declared that 100% of the villages were connected to the central electric grid [1], based on a metric that a village is grid connected if at least 10% of households in each village were connected [2]. The GOI, under the Saubhagya (Pradhan Mantri Sahaj Bijli Har Ghar Yojana) scheme, aimed 100% of households to be connected to the electric grid by March 2019 [3]. As on March 31, 2019, they have reached 99.99% of households as per the official website of Saubhagya [4]. However, in reality many states are struggling with unreliable electricity supply, especially in the night time, voltage fluctuations, unannounced load shedding, and frequent power outages [3]. The United Nations, has emphasized decentralized solar power as a way to achieve Sustainable Development Goal 7 (SDG 7) and, the Sustainable Energy for All (SE4ALL) initiative and fulfil the promise of universal energy access by 2030 [5].

Decentralized solar solutions are promising, and provide affordable lighting to households in remote rural areas [6–8]. Households in remote rural areas, lacking access to the central electric grid, are deprived of adequate electricity and stand to benefit more from solar-based power generation. Solar lamps have generation capacities in the range of 1–1.5 Wp, and solar home lighting systems have capacities in the range of 20–100 Wp. Portable solar lamps are not a substitute for central electric grid but they are the fastest, most immediate, and most economical solution for rural families who lack access to adequate electricity [6,9].

According to Mainali and Silveira [10], Khan [11], and Urpelainen and Yoon [12], informational barriers play an important role in the adoption of technology. In many rural populations, a lack of awareness of solar products is a major obstacle in developing the solar energy market [13,14]. In a study conducted by Urpelainen and Yoon [12] in 2015, it was found that rural households in Uttar Pradesh, India were unaware of solar home systems (SHS). If they were aware of SHS, then they did not know where to buy them or to have them repaired [15].

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Abbreviations

A&D	Assembly and Distribution
APL	Above Poverty Line
BPL	Below Poverty Line
GARV	Grameen Vidyutikaran
GoI	Government of India
MNRE	Ministry of New and Renewable Energy
MSP	Million Solar Urja Lamp Program
PDS	Public Distribution System
PV	Photovoltaic
R&M	Repair and Maintenance
Saubhagya	Pradhan Mantri Sahaj Bijli Har Ghar Yojana
SDG	Sustainable Development Goal
SE4ALL	Sustainable Energy for All
SHS	Solar Home Systems
SoULS	Solar Urja through Localization for Sustainability
Wp	watt-peak
WTP	Willingness to pay

Solar projects have failed due to poor public awareness, lack of participation by the local population in solar lighting projects and lack of after-sales services [16,17]. This has led to less demand for solar products, especially in energy-poor rural areas.

Understanding the factors that influence household's willingness to pay (WTP) for solar products is essential for the successful adoption of solar technology. In this study, we explore household's awareness of solar products, household's perception of solar lamps, duration of electricity available during dark hours, kerosene devices for lighting, and household's motivation to adopt solar technology and their influence on user's willingness to pay for solar products.

This article is organized as follows: Section 2 describes the Solar Urja through Localization for Sustainability (SoULS) project, which started in 2017 with the aim of distributing solar lamps to students in energy-deprived communities in rural India; Section 3 explains the study aim and design; Section 4 outlines descriptive statistics of households who participated in the four rounds of a survey and presents the longitudinal logistic regression results on factors influencing household's WTP; Section 5 is a discussion of the findings and the interaction effects of different factors on WTP; and the final section offers concluding remarks.

2. Solar Urja through Localization for Sustainability (SoULS) initiative

The SoULS initiative is modeled on the pilot, the Million Solar Urja Lamp Program (MSP) [6,21,22]. The pilot MSP program initiative was implemented by Indian Institute of Technology (IIT) Bombay in four Indian states - Madhya Pradesh, Maharashtra, Rajasthan, and Odisha - from February 2014 to March 2016 [6,23]. The objective of the MSP was to provide clean and affordable solar lamps to the most marginalized and deprived communities. More than 1500 local community members were trained to assemble, distribute, repair and maintain the lamps. The solar lamps were sold at a subsidized rate of 120 INR (~1.72 US$).[1] Free after-sales service for a year was provided through trained locals to ensure households had access to repair services and could continue using them. The program covered 23 districts, 97 sub-districts and more than 10,900 villages. There were 54 assembly and distribution (A&D) centers and 350 repair and maintenance (R&M) centers in operation under the program, with training provided to 1409 local people.

Leveraging the insights from MSP, IIT Bombay, with the funding from the Ministry of New and Renewable Energy (MNRE) of the Government of India, implemented the SoULS initiative [6,16,21,22]. This initiative substantially scaled the pilot MSP. This flagship scheme of the MNRE is arguably the largest decentralized solar lamp dissemination program in the world. Under this initiative, 6.06 million solar lamps were distributed in four Indian states of Assam, Bihar, Jharkhand, and Uttar Pradesh – from January 2017 to December 2019. More than 7436 local people were trained to assemble, distribute, repair and maintain the lamps [24]. Free after-sales service for a year was provided through trained locals to ensure households had access to repair services and could continue using them. The program covered 62 district, 225 blocks

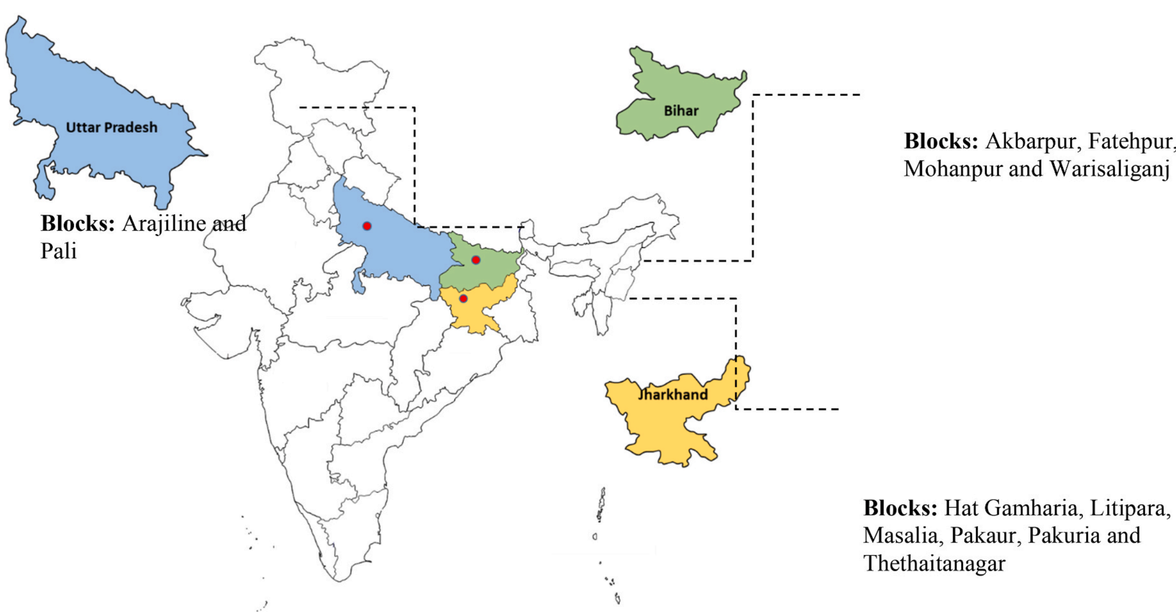

Fig. 1. Survey locations (blocks in states) in India.

[1] Assuming 69.68 INR is approximately 1 US$.

and approximately 11,887 villages, there were 193 A&D centers and 1769 R&M centers in operation under this initiative.

This initiative was implemented in remote rural areas of India to provide clean, affordable, and reliable solar lamps. The GARV[2] data state report (Dec 2016) generated by the Ministry of Power, India was utilized to select villages based on the following criteria: 1) low electrification rate 2) higher dependency on kerosene for lighting purpose 3) energy deprivation. The villages selected had household electrification of less than 50% and 50% of households were dependent on kerosene. The distribution of solar lamps was undertaken in schools, and was targeted toward the school-going children of the rural poor households. Thus, the beneficiaries received solar lamps at the subsidized cost of INR 100 (~1.43 US$). The SoULS project's distribution scheme was implemented in such a way that more than 60% of the total enrolled school students in each of the blocks would receive solar lamps. The SoULS initiative pushes for the development and dissemination of solar products through localized mechanisms, that can be sustained over a period of time. The initiative explores permanent and reliable solar solutions for households in remote rural areas, where the reliability and availability of electricity is poor. As the reliability and availability of electricity in these villages are poor, there is a potential to develop a local low-cost sustainable solar market.

3. Study aim and design

This study was conducted as a part of the SoULS initiative. The primary aim of the study was to explore the determinants of the WTP by the beneficiaries for solar lamps.

A sample of the households was selected for this study. The sample included a random selection of 1159 households from 32 villages in 12 blocks in the state of Bihar, Jharkhand, and Uttar Pradesh (see Fig. 1). Those households having school-going children were eligible to receive the solar lamps through schools, as part of the SoULS initiative. Having a control sample was not possible to undertake this study. As per the mandate of the SoULS initiative, no eligible and interested household would be prevented to own or purchase a solar lamp. Thus, we adopted a quasi-experimental approach using an interrupted time-series design [25]. In an interrupted time-series design, a routine situation of targeted community is "interrupted" by a treatment (in this study: a solar lamp). Measurement of the outcome (in this study: WTP) is then undertaken at multiple time points after the treatment [25]. Interrupted time-series design are like pretest-posttest design, with a difference that the former includes multiple posttest measurements of the outcome variable [25,26].

A third-party survey company was hired to conduct the longitudinal field surveys in the regional language of respective states, Hindi. Third-party field investigators were trained by authors and a pilot was conducted prior to surveying participants of this study. Every village visit was supervised by one of the authors who themselves did not conduct any interviews. The research data were cleaned by the third-party survey company and then sent to the authors for analysis. Data collection for this study overlapped with the implementation of this initiative for the selected households. Baseline (BL) data were collected at the start of solar lamp intervention in these villages during April 2018. The post-test measurement data were collected in three follow-up rounds: Follow up 1 (FU1) in June 2018; Follow up 2 (FU2) in November 2018; and Endline (EL) in March 2019 (see Table 1). The survey included household, village, and block level questions to particularly explore the social, environmental and economic factors of the study households. The data includes information on household demographics, educational outcomes of children, economic, social, health outcomes of the households, etc. This study focuses on examining households' willingness to pay for solar lamps at a market price of INR 600 (~8.61 US$). Market price of solar lamp was set at INR 600 (~8.61 US$), after considering raw material kits cost of INR 450 (~6.45 US$) per solar lamp including logistics, operational cost of assembly and distribution of lamps and a marginal profit. Operational cost covered manpower and logistics towards assembly, distribution, emoluments to provide free repair-maintenance service, and overheads.

3.1. Data analysis

To examine the relationship between the households' ability to purchase[3] solar lamps at market price as an indicator of WTP and the different predictor variables, a logistic regression on longitudinal binary outcome was performed. The longitudinal logistic model [27,28] investigates transformation of an outcome variable, repeatedly measured at various time points for each household or person using time as a predictor of an outcome variable (Y_{it}). The longitudinal logistic regression is modeled in the following way:

$$\mathrm{logit}(Y_{it}) = \alpha + \beta X_{it} + \varepsilon_{it}$$

Where Y_{it} is an outcome variable estimated for each household and each time point, α is the intercept, β are the regression coefficients, X_{it} are the predictor variables, and ε_{it} is the error term. Conditional fixed and random effects by village are also included in the model [28,29].

3.2. Outcome and predictor variables

We estimated the households' WTP for solar lamps at market price through respondents' self-reported answers. This variable is the measure of the respondents WTP for solar lamps versus the demand for solar lamps in energy-poor rural areas. The question on WTP for solar lamps, which is the key dependent variable in this study, was as follows: "Would it be possible for you to buy the solar lamp at the market price of 600 INR (~8.61 US$)". The response categories were "Yes" or "No". Table 2 shows the predictor variables which are used in the longitudinal logistic regression analysis.

3.3. Limitation of study

Respondents' self-reported measures are the limitation of the study because self-reported answers are sensitive to bias. However, this study could be foundational and germane for future research wherein market transactions could be used to estimate consumers' willingness to pay.

4. Results

4.1. Descriptive statistics

Table 3 presents the descriptive statistics of households who participated in four survey rounds. A notable feature of the study is that 95% of respondents were the same respondents who answered from each household on each survey round. The description of the variables is given below in greater detail.

4.1.1. Demographics

The proportion of male respondents was high (59%) and about 44% respondents had no formal education. Caste of the respondents, households with PDS cards, and household size were the same in the four rounds of survey. Fifty-six percent of the respondents belonged to other

[2] Grameen Vidyutikaran (GARV) App launched by Government of India to monitors the village and household electrification level in the country.

[3] Possibility of purchasing indicates the purchase intention of consumers to buy a product or service in the future. In short, it simply demonstrates the purchasing behavior of the consumer [18]. Earlier studies show that the increase in the possibility of purchase reflects the willingness to purchase or purchase intention of the consumers [19,20].

Table 1
Household distribution by state, blocks, and villages.

State	Number of blocks	Number of villages	Households Surveyed			
			Baseline (April 2018)	Follow up −1 (June 2018)	Follow up −2 (November 2018)	Endline (March 2019)
Bihar	4	10	526	526	526	526
Jharkhand	6	15	331	331	331	331
Uttar Pradesh	2	7	302	302	302	302
Total	**12**	**32**	**1159**	**1159**	**1159**	**1159**

Table 2
Predictor variables in the longitudinal logistic regression analysis of willingness to pay for solar lamps at market price.

Predictor	Variables
Demographic predictors	Gender, Education, Caste, Public distribution system (PDS) Card, Household size, and Geographical areas (see Table 1)
Affordability predictors	Household's last month income
Kerosene use predictors	Monthly kerosene expenditures and Kerosene based devices used for lighting
Electricity predictors	Electric grid connection and Duration of availability of electricity in dark hours
Solar energy predictors	Solar lamp better than kerosene lamp for lighting, Knows subsidized price of solar lamp, Heard of Free Repair and Maintenance warranty, Awareness of various solar products and Motivation to adopt solar technology

backward caste followed by scheduled tribe (22%), scheduled caste (16%) and general category (6%). 60% of the households surveyed were below the poverty line and 10% were in the poorest of the poor category (i.e., Antyodaya[4]). The mean number of family members in each household was 6 people on average.

4.1.2. Affordability

The average last month's income of the households varied between INR 4775 (~68.53 US$) to INR 5428 (~77.90 US$) over time.

4.1.3. Kerosene

The mean number of kerosene-based devices used for lighting in households was two but the proportion of households using kerosene had decreased by 3% between the first and the last round of surveys. However, the average monthly kerosene expenditures of the households had slightly increased from INR 105 or 1.50 US$ ($N^{5}_{BL} = 1055$) to INR 118 or 1.69 US$ ($N_{EL} = 1020$).

4.1.4. Electricity

In the baseline survey, about 84% households had electricity connections, whereas in the endline survey, 94% of the sample had electricity at house. The duration of electricity available in the grid-connected households between 6 p.m. and 6 a.m. had increased from 6.46 h to 8.33 h from the baseline survey to the endline survey.

4.1.5. Solar energy

Throughout the rounds of surveys, the households' perception of the usage of solar lamps for lighting purposes enhanced positively as compared to kerosene lamps. In Baseline, only 7% of the respondents knew the subsidized price of solar lamps, while 34%, 62%, and 75% of respondents knew the subsidized price of solar lamps in the Follow-1, Follow-2 and Endline surveys respectively. Table 3 demonstrates how households' awareness of various solar products and their motivation to adopt solar technology increased over time, shown by the weighted average scores.

4.1.6. Outcome variable

The percentage of respondents with the WTP for solar lamp at the market price of INR 600 (~8.61 US$) increased by around 40%, between the first and last surveys as shown in Table 3.

4.2. Longitudinal logistic regression models

In Table 4, we present results from the ordinary longitudinal logistic regression analysis i.e., Model 1, along with random and conditional fixed effects by village in Model 2 and Model 3. In the models that demonstrated WTP based on house characteristics, we found positive and consistent connections with the highest education level (i.e., Postgraduate), number of kerosene-based devices used for lighting in the households, households' perception about solar lamps versus kerosene lamps, knowledge about subsidy, awareness of various solar products, and motivation to adopt solar technology. In the random and fixed effects models broken up by village, we found that caste demarcation has significant associations with the intention to purchase a solar lamp. Households of general caste are more likely to purchase solar lamps at market price, compared to other backward and scheduled caste. Each additional kerosene device in household increases the WTP for solar lamps at market price by 16–20%.

A notable observation is that the monthly expenditure on kerosene shows a negative but not significant correlation in all 3 models. The positive perception for solar lamps in the households as compared to kerosene lamps increases the willingness to pay for solar lamps by 60–71%. Households are more interested to purchase solar lamps at a subsidized price over time. However, despite knowing the subsidized rate of solar lamp, these households are willing to buy solar lamps at the market rate. The variable for knowing subsidized price of the solar lamp, which we included in all the models is positive, statistically significant and consistent for WTP in all three models. Household's motivation to adopt solar technology was measured by scoring 13 items on 5-point Likert scale (see Table A.1 in Appendix A for the items used in the scale and scores). This demonstrated that households are interested to purchase solar lamps as a lighting source, if they have a higher motivation to adopt solar technology. We found that with higher motivation, the likelihood that households would purchase a solar lamp at the market price increased from 24% in baseline to 35% in endline.

The awareness about various solar products follows increasing trend over four survey rounds (see Table B1 in Appendix B for awareness of various solar products). SoULS project employees conduct awareness campaigns in the schools and villages about solar technology products. These campaigns may have improved awareness of the households

[4] Antyodaya ration card is given to the poorest families having no steady income. These cards are issued to such families who have an income of less than 250 INR (~3.6 US$) per capita per month. Unemployed people, old age men, women, and laborers come under this category (https://www.aazad.com/should-know/types-of-ration-card-in-india.html).

[5] N = Number of sample size.

[6] The count gives the proportion of respondents who answered "Yes" for various solar products, and the score is then calculated as a weighted average.

[7] Scores are evaluated based on 5-point Likert scale. Respondents' answers are rated if they Strongly agree (5), Agree (4), Neutral (3), Disagree (2), and Strongly disagree (1), and the score is then calculated as a weighted average of 13 questionnaires.

Table 3
Descriptive statistics for the household characteristics.

characteristics.	Predictor Variables	Baseline (April 2018)	Follow-1 (June 2018)	Follow-2 (November 2018)	Endline (March 2019)
Demographic Predictors	Gender				
	Male	746 (64%)	684 (59%)	683 (59%)	684 (59%)
	Female	413 (36%)	475 (41%)	476 (41%)	475 (41%)
	Education				
	No formal education	482 (42%)	509 (44%)	506 (44%)	506 (44%)
	Primary education	215 (19%)	151 (13%)	145 (13%)	148 (13%)
	Secondary education	144 (12%)	209 (18%)	224 (19%)	217 (19%)
	High School	177 (15%)	151 (13%)	142 (12%)	150 (13%)
	Intermediate	84 (7%)	80 (7%)	85 (7%)	82 (7%)
	ITI/Diploma	5 (0.4%)	4 (0.3%)	2 (0.2%)	3 (0.4%)
	Graduate	43 (4%)	44 (4%)	41 (4%)	44 (4%)
	Post-graduate	9 (0.6%)	11 (0.7%)	14 (0.8%)	9 (0.6%)
	Caste Group				
	General	69 (6%)	69 (6%)	69 (6%)	69 (6%)
	Other backward	648 (56%)	648 (56%)	648 (56%)	648 (56%)
	Scheduled caste	187 (16%)	187 (16%)	187 (16%)	187 (16%)
	Scheduled tribe	255 (22%)	255 (22%)	255 (22%)	255 (22%)
	PDS Card				
	Antyodaya	119 (10%)	119 (10%)	119 (10%)	119 (10%)
	Below Poverty Line (BPL)	698 (60%)	698 (60%)	698 (60%)	698 (60%)
	Above Poverty Line (APL)	115 (10%)	115 (10%)	115 (10%)	115 (10%)
	No card and others	227 (20%)	227 (20%)	227 (20%)	227 (20%)
	Household Size	6 (2)	6 (2)	6 (2)	6 (2)
Affordability related predictor	**Households last month income (INR)**	4775 (3581)	5427 (3451)	5428 (3311)	5324 (3292)
Kerosene related predictors	**Household using kerosene**	1055 (91%)	1077 (93%)	1019 (88%)	1020 (88%)
	Kerosene based devices used for lighting	2 (1)	2 (1)	2 (1)	2 (1)
	Monthly kerosene expenditures (INR)	105 (58)	95 (53)	111 (58)	118 (382)
Electricity related predictors	**Electricity connection**	976 (84%)	1059 (91%)	1085 (94%)	1085 (94%)
	Duration of electricity available between 6 p.m.-6 am (hours)	6.46 (2.94)	6.45 (2.19)	8.10 (2.26)	8.33 (2.09)
Solar Energy related predictors	**Solar lamp better than kerosene lamp for lighting**				
	Yes	471 (41%)	842 (73%)	575 (50%)	770 (66%)
	No	688 (59%)	317 (27%)	584 (50%)	389 (34%)
	Knows subsidized price of solar lamp				
	Yes	76 (7%)	390 (34%)	721 (62%)	888 (75%)
	No	1083 (93%)	769 (66%)	438 (38%)	293 (25%)
	Heard of Free Repair and Maintenance warranty				
	Yes	27 (2%)	108 (9%)	267 (23%)	430 (37%)
	No	964 (83%)	1030 (89%)	826 (71%)	703 (61%)
	Not Sure	168 (14%)	21 (2%)	66 (6%)	26 (2%)
	Awareness of various solar products (Score[6])	0.06	0.27	0.31	0.51
	Motivation to adopt solar technology (Score[7])	3.4	3.8	3.7	4.2
	Outcome Variable				
Outcome variable	**Willingness to pay for solar lamp at market price of 600 INR**				
	Yes	326 (28%)	540 (47%)	498 (43%)	792 (68%)
	No	833 (72%)	619 (53%)	661 (57%)	367 (32%)

Notes: Our unit is household. 95% respondents are the same throughout our study. Data are number (%) or mean (SD).

about solar products. Majority of the respondents (92%) reported that they came to know about solar products either from neighbors, relatives or friends and through their children via school. Other media outlets, such as radio, pamphlets, and newspapers, were less influential. WTP for solar lamps has higher positive odds with awareness of various solar products. Compared to the baseline survey, higher positive odds for WTP were observed in the Follow-up 1, Follow-up 2, and Endline survey. Moreover, the households of Jharkhand and Uttar Pradesh were more interested to purchase solar lamps at the market price, compared to Bihar, as shown in Table 4. Other factors like PDS card, household size, monthly kerosene expenditure, duration of electricity available between dark hours, and information about free repair and maintenance warranty were not responsible for the change in households WTP.

5. Discussion

This manuscript draws on the literature on willingness to pay for solar lamps in rural households and awareness of solar PV products. Urpelainen and Yoon [12] state that there is plenty of scope for improving awareness about solar products in India while Mainali and Silveira [10] reported that WTP of user's to access electricity and awareness levels in adopting RE-technologies is increasing significantly. According to Komatsu et al. [30], non-income factors like kerosene consumption have a significant role in the dissemination of SHS in rural Bangladesh. Lay et al. [8] reported that the income and education were the key determinants of SHS adoption. Initial cost of installation of SHS is the main barrier for the base of the pyramid population (Halder [14]) and high initial subsidies are necessary to make solar products affordable for end users (Yoon et al. [9]). Another study highlights that educating women on solar products, improving level of awareness and knowledge of the community by installing solar systems in the community can help adoption of solar products (Rebane and Barham [13]). This study also extends the current understanding about the factors influencing WTP for solar lamps in rural India as explained in following subsections.

5.1. Demographics and WTP

5.1.1. Gender of the respondent

Women in rural areas spend more time inside the home, therefore, their lighting need is higher compared to men. Consequently, the possibility that women will adopt solar technology should be higher than

Table 4
Longitudinal logistic regression of WTP for solar lamp at market price of 600 INR on household variables.

	Model 1 (Ordinary logit)			Model 2 (Random Effect)			Model 3 (Fixed Effect)		
	Log Odds (Std. Error)	Odds ratio	p-value	Log Odds (Std. Error)	Odds ratio	p-value	Log Odds (Std. Error)	Odds ratio	p-value
Gender									
Male (vs Female)	0.12 (0.09)	1.13	0.18	0.02 (0.10)	1.02	0.85	0.00 (0.10)	1.00	0.97
Education Level									
Primary Education (vs No formal Education)	0.25 (0.13)	1.29	0.04	0.17 (0.13)	1.19	0.19	0.17 (0.13)	1.18	0.20
Secondary Education (vs No formal Education)	0.26 (0.12)	1.30	0.02	0.10 (0.12)	1.11	0.39	0.10 (0.12)	1.11	0.42
High School (vs No formal Education)	0.31 (0.13)	1.37	0.02	0.11 (0.14)	1.12	0.44	0.10 (0.14)	1.10	0.52
Intermediate (vs No formal Education)	0.36 (0.18)	1.43	0.04	0.14 (0.19)	1.15	0.46	0.10 (0.19)	1.11	0.58
ITI/Diploma ((vs No formal Education)	0.14 (0.87)	1.15	0.87	−0.06 (0.86)	0.94	0.95	−0.07 (0.85)	0.93	0.93
Graduate (vs No formal Education)	−0.11 (0.23)	0.90	0.66	−0.11 (0.24)	0.90	0.67	−0.08 (0.24)	0.92	0.73
Post-graduate (vs No formal Education)	1.13 (0.53)	3.09	0.03	0.96 (0.55)	2.60	0.08	0.94 (0.56)	2.57	0.09
Caste Group									
Other Backward Caste (vs General)	−0.08 (0.19)	0.92	0.68	−0.54 (0.23)	0.58	0.02	−0.63 (0.24)	0.53	0.01
Scheduled Caste (vs General)	0.03 (0.22)	1.03	0.89	−0.51 (0.26)	0.60	0.04	−0.60 (0.26)	0.55	0.02
Scheduled Tribe (vs General)	−0.29 (0.24)	0.75	0.22	−0.40 (0.29)	0.67	0.17	−0.37 (0.31)	0.69	0.23
PDS Card									
Antyodaya (vs Above Poverty Line)	−0.20 (0.18)	0.82	0.28	−0.26 (0.19)	0.77	0.16	−0.27 (0.19)	0.76	0.15
Below Poverty Line (vs Above Poverty Line)	−0.11 (0.14)	0.90	0.47	−0.13 (0.15)	0.88	0.40	−0.13 (0.15)	0.88	0.40
Others (vs Above Poverty Line)	−0.26 (0.17)	0.77	0.12	−0.19 (0.18)	0.83	0.27	−0.19 (0.18)	0.83	0.30
Household Size	0.00 (0.02)	1.00	0.88	−0.01 (0.02)	0.99	0.56	−0.01 (0.02)	0.99	0.53
Household last month income (INR)	0.00 (0.00)	1.00	0.002	0.00 (0.00)	1.00	0.03	0.00 (0.00)	1.00	0.03
Monthly Kerosene expenditure (INR)	0.00 (0.00)	1.00	0.42	0.00 (0.00)	1.00	0.48	0.00 (0.00)	1.00	0.48
Kerosene based devices used for lighting	0.15 (0.06)	1.16	0.006	0.18 (0.06)	1.20	0.001	0.18 (0.06)	1.20	0.002
Duration of electricity available between 6 p.m.-6 am (hours)	0.03 (0.03)	1.03	0.24	0.02 (0.03)	1.02	0.45	0.02 (0.03)	1.02	0.52
Solar lamp better than kerosene lamp for lighting	0.54 (0.09)	1.71	<0.0001	0.48 (0.09)	1.61	<0.0001	0.47 (0.09)	1.60	<0.0001
Knows subsidized price of solar lamp (vs No)	0.53 (0.10)	1.70	<0.0001	0.36 (0.11)	1.44	0.001	0.34 (0.11)	1.40	0.003
Heard of Free Repair and Maintenance warranty									
Yes (vs No)	−0.13 (0.12)	0.88	0.27	−0.07 (0.13)	0.93	0.54	−0.06 (0.13)	0.94	0.63
Not sure (vs No)	−0.29 (0.19)	0.75	0.12	−0.36 (0.20)	0.70	0.08	−0.37 (0.20)	0.69	0.07
Awareness of various solar products	1.05 (0.23)	2.86	<0.0001	1.17 (0.25)	3.23	<0.0001	1.16 (0.25)	3.19	<0.0001
Motivation to adopt solar technology	0.22 (0.12)	1.24	0.06	0.29 (0.12)	1.34	0.02	0.30 (0.12)	0.30 (0.12)	0.01
Events									
Follow up 1 (vs Baseline)	0.56 (0.14)	1.75	<0.0001	0.63 (0.15)	1.87	<0.0001	0.63 (0.15)	1.87	<0.0001
Follow up 2 (vs Baseline)	0.16 (0.15)	1.17	0.29	0.23 (0.16)	1.26	0.15	0.24 (0.16)	1.27	0.14
Endline (vs Baseline)	1.00 (0.19)	2.71	<0.0001	1.09 (0.21)	2.98	<0.0001	1.10 (0.21)	3.01	<0.0001
Geographical areas									
Jharkhand (vs Bihar)	1.43 (0.17)	4.16	<0.0001	1.29 (0.34)	3.64	0.0001	–		–
Uttar Pradesh (vs Bihar)	2.64 (0.15)	14.07	<0.0001	3.17 (0.37)	23.88	<0.0001	–		–
Akaike information criterion (AIC)	3875.3			3738			3515.6		
Negative log likelihood	−1906.65			−1838			−1729.81		

Notes: Odds ratios above one indicate higher possibility of purchasing solar lamps at market price. Random and fixed effects are at the village level. In fixed effect model (Model 3) variable “geographical areas” is dropped because it is time invariant and get cancelled.

men. Result indicates that willingness to pay for solar lamps in women is lower as compared to men, but the effect is not very significant. This finding is consistent with Urpelainen & Yoon [12] study where they reported that willingness to pay for SHS by female respondents was lower and the effect was not very significant. They also reported that men in the households in rural India have more authority to make a decision to purchase utilities, compared to women.

5.1.2. Education

In the last eight years, most research on the use of solar products in rural energy-poor households has not considered the effect of respondents' education level on solar technology adoption [13,30]. Lay et al. [8] study showed that higher education has a weak positive effect on household solar energy use. However, according to the recent study of Urpelainen et al. [12], the education level of the respondents did influence the adoption of solar technology. In this study, each level of additional education of respondents shows a positive but insignificant correlation with WTP, except for post-graduate respondents. Whereas, all three models show the respondent's WTP increases positively and significantly with postgraduate education. This finding is consistent with previous studies on WTP for solar lanterns and SHS, as reported in Yoon, Urpelainen, & Kandlikar [9] and Urpelainen & Yoon, [12].

5.1.3. Caste

Previous studies in India on the adoption of cleaner energy shows that the households of forward caste are more likely to adopt cleaner energy as compared to households of backward caste [31]. Broadly, there are four main caste groupings in India- General/Forward caste, Scheduled tribes (STs), Scheduled Castes (SCs) and Other Backward castes (OBCs). General caste members are considered the least disadvantaged groups. The tribes that have traditionally lived in the forests and have been added under a "schedule" of the constitution of India are called 'Scheduled Tribes (STs)'. OBCs form a large group that is heterogeneous and is considered by the constitution of India as being "economically and socially backward". SCs have traditionally been marginalized and not in the mainstream of the society. OBCs, SCs, and STs are economically and socially backward communities. OBCs, SCs, and STs are provided with job reservations in the central and also in state government systems to increase their representation in the mainstream society, and to simultaneously improve their economic and social well-being. OBCs, SCs, and STs are normally and collectively referred to as lower castes [32].

A study of Urpelainen & Yoon [12] on WTP for SHS reports that caste of the respondents does not have an effect on WTP. Notably, regression results with conditional fixed and random effects by village demonstrate the role of caste on WTP. Results indicate that general caste households are more willing to pay for solar lamps than other backward and scheduled caste households, the finding is consistent with Gundimeda & Köhlin [31].

5.1.4. Geography

Previous studies on solar lamps/lanterns are limited by the general conclusions made by studies conducted in a few geographical areas at a time [9]. Results from a large sample in different geographical areas can be applied to other rural areas in India as well. Experimental results demonstrated that the households of Jharkhand and Uttar Pradesh were more willing to purchase solar lamps at the market price, compared to Bihar. Results on awareness levels, are fully consistent with the study conducted by Urpelainen & Yoon [12] on awareness levels and WTP of SHS in the state of Uttar Pradesh, India.

5.2. Affordability and WTP

Earlier studies reveal that household income has a positive effect on the adoption of solar technology [7–9,12,13,30,33]. Our findings, based on the households' last month income and WTP, are consistent with existing studies on solar technology adoption.

5.3. Kerosene and WTP

In rural areas of India, kerosene is mainly used for lighting and to some extent for cooking and heating water. In 2011, more than 380 million people in rural areas of India were using kerosene for lighting purposes [34,35]. If a family invests more in kerosene for lighting, it may indicate that their daily lighting need is higher. In our results, monthly kerosene expenditure does not show a relationship with WTP, contrary to Urpelainen and Yoon's [9] findings, which claimed a significant association between WTP and monthly kerosene spending.

Households who believe that using solar lamps will improve the quality of lighting and are better than kerosene lamps may show their interest and are willing to purchase solar lamps. Households with a higher number of kerosene-based devices for lighting purposes may view a solar lamp as an option for clean lighting, increasing the demand for solar products in these households. Previous studies did not consider the number of kerosene-based devices used for lighting in households as a factor in predicting WTP for solar lamps. This study finds that each additional kerosene device in the household increases the WTP for solar lamps, shedding light on the added value of this research.

5.4. Electricity and WTP

Previous studies considered the effect electricity connection in household has on adoption of solar technology [7,12,30]. Urpelainen & Yoon [12] found that households with electricity in Uttar Pradesh were more willing to pay for SHS, potentially due to the unreliable supply of electricity [12].They suggested future studies should include the quality of household electricity supply. Therefore, in this paper, the duration of electricity available during dark hours along with household's electricity connectivity is included. Duration of available electricity in the grid-connected households between 6 p.m. and 6 am has increased over time in all surveyed states. Positive but no significant relation was found between the duration of electricity available during dark hours and WTP.

5.5. Solar energy and WTP

Research on awareness of various solar products in rural areas reveals that the market of the solar product is hampered by a lack of awareness [13] which leads to consumers unwillingness to pay for solar technology. A recent study by Urpelainen and Yoon [12] also noticed a lack of awareness of the SHS in rural areas of Uttar Pradesh, India. This study shows that households awareness of various solar products has increased over time. In the baseline survey, only 21% of the respondents had heard of solar lanterns and less than 2% had heard of solar home system, solar mobile chargers, and solar water pump. At the endline survey, about 97% and 60% of the respondents came to know about solar lanterns and solar mobile charger respectively but still only 26% of people were aware of the solar water pump and only 24% were aware of the solar home system. This study also reveals that there is large need for increasing awareness in Bihar, Jharkhand and Uttar Pradesh especially for solar home systems and solar water pumps.

The decision to purchase solar energy products depends on the household's' motivation for the adoption of solar technology. Households' motivation to adopt solar technology has increased over time. Results demonstrated that the households' WTP for solar lamps at the market price increased with their motivation to adopt solar technology (see Fig. 2(a)), however, it is significantly influenced by an awareness of various solar products (see Fig. 2(b)).

5.6. Interaction effects of different factors on WTP

In all the models (i.e., ordinary longitudinal logistic regression

(Model 1), random effect (Model 2) and fixed effect (Model 3)) of WTP for solar lamp at market price, there were strong, significant and consistent connections between: households' last month income, number of kerosene-based devices used for lighting in the households, households' perception about solar lamps versus kerosene lamps, knowledge of subsidized price of solar lamp, awareness of various solar products, and motivation to adopt solar technology. Model 3 with lowest AIC value (3515.6) is the most stable and fitted model to predict the likelihood of households WTP for solar lamps at market price using only significant variables.

The findings of this study demonstrate that the effect of affordability (i.e., households last month income) on WTP is significantly moderated by awareness of solar products and their motivation to adopt solar technology. Fig. 3 provides the predicted probabilities of WTP, as a function of affordability moderated by two indicators: awareness of various solar products, and households' motivation to adopt solar technology, adjusting for other predictors. There is an increased probability of willingness to pay for solar lamp at the market price when

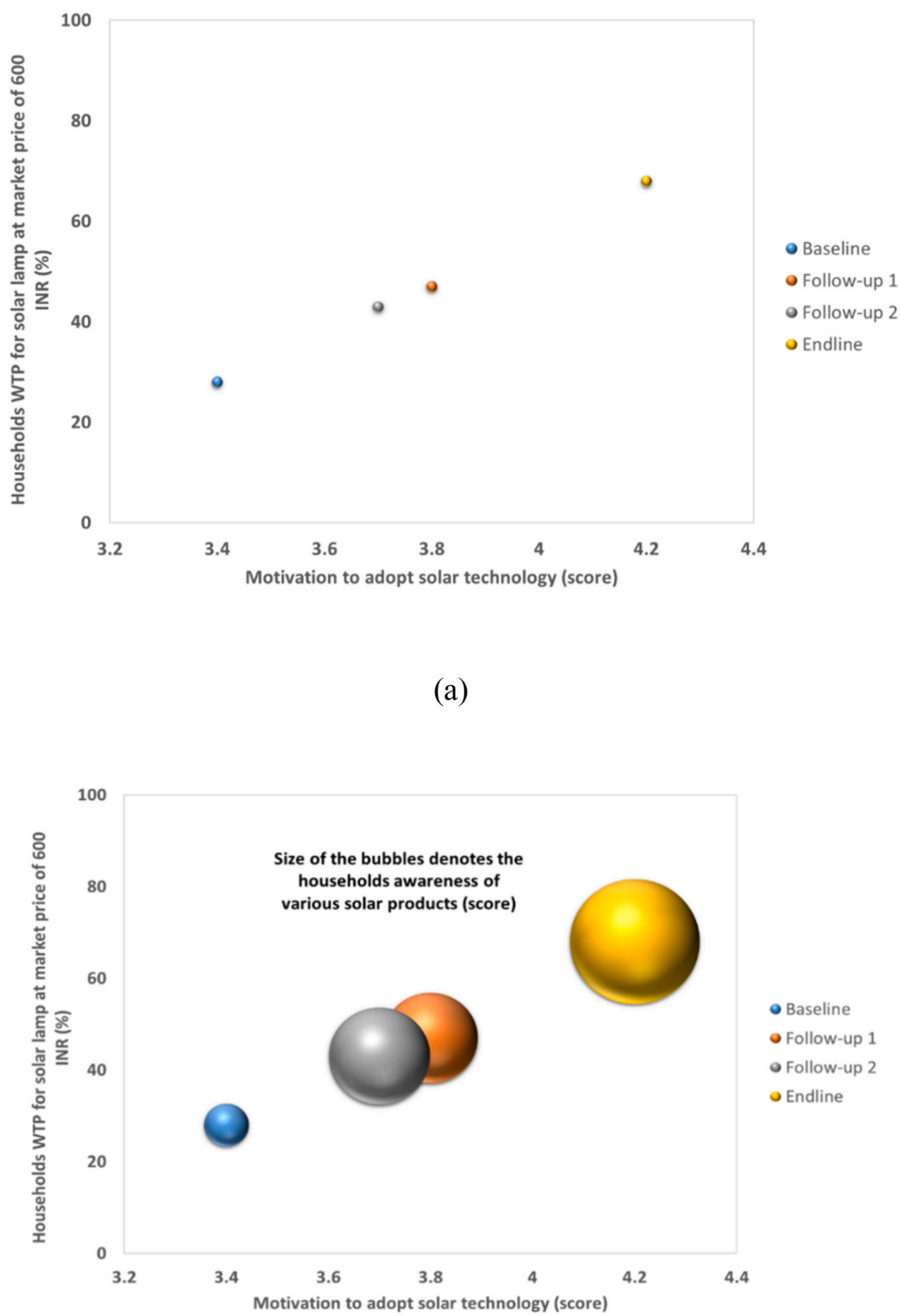

Fig. 2. (a) Households' WTP for solar lamps at market price across time and (b) Households' WTP for solar lamps at market price with households awareness of various solar products across time.

households' income increases but there are some differences due to different levels of awareness of various solar products and households' motivation to adopt solar technology.

Those households who are not motivated to adopt solar technology and are also not aware of solar products are least likely to purchase solar lamps at all income levels. At the same time, household's' awareness of solar products or household's' motivation to adopt solar technology does enhance the probability of purchasing solar lamps, compared to the previous case. Fig. 3 also highlights that awareness of various solar products, coupled with household's' motivation to adopt solar technology does significantly raise the probability of WTP for solar lamps when the household's' last month's income increases.

6. Conclusion

This paper makes new contributions to the socio-technical research of the pico-photovoltaic (pico PV) system (solar lamps or lanterns) by examining factors that influence the WTP for solar lamps. WTP indicates the intention of consumers to buy a product or service in the future. Understanding the factors that influence households' WTP for solar products is essential for the successful adoption of technology. Furthermore, in the context of solar pico PV products, similar longitudinal study with heterogeneity in geographical representation and large sample size has not been undertaken to understand the causal relationship among the various factors influencing willingness to pay at market price and their impact over time.

The findings on WTP for solar lamps, household's awareness of various solar products, public perception on solar lamps, and motivation to adopt solar technology are new and contribute to the growing body of research on the adoption of solar products. Longitudinal logistic regression results provide insights into the relationship between various household variables and that household's WTP for solar lamps at market price.

This article examined the relationship of various household variables with the household's WTP for solar lamps at market price by surveying three energy-poor states of Bihar, Jharkhand, and Uttar Pradesh. In a period of one year at different time points, awareness of different solar products, motivation to adopt solar technology, WTP for solar lamp at market price, and other various factors in rural households was analyzed. This study focuses on different geographic areas, where the reliability and availability of electricity are poor and there is the possibility to grow the demand and market for solar products. It was observed that the awareness of solar products, such as solar lantern and solar mobile charger, increased over time. Also, over time, an increase in the number of households' willing to purchase solar lamps at the market price was observed.

Result indicates that the highest qualification, a higher number of kerosene based devices in the households, households' perception of solar lamps, awareness of solar products, and motivation to adopt solar technology are the strongest predictors of WTP for solar lamps at market price across all models. Duration, or mean hours of electricity available, in the grid-connected households between 6 p.m. and 6 am has increased over the period of time in all surveyed states and we found positive, but not significant connection, with WTP. These findings offer a new contribution to the socio-technical research of solar lamps or lanterns.

Patterns of households' awareness of solar products, motivation to adopt solar technology and their interest in solar lamps over time was examined. Across time, an increase in households' level of awareness, motivation, and WTP for solar lamps at market price was observed. It can be predicted that household's awareness of solar products coupled with motivation to adopt solar technology does significantly raise the probability of WTP for solar lamps when the household's income increases.

Results also suggest that there is a large need to increase awareness in Bihar, Jharkhand and Uttar Pradesh, especially for SHS and solar water pumps. In these states, the duration of available electricity, especially in dark hours, is still very minimal, and solar products can serve as a meaningful way to close these gaps. Therefore, results recommend that awareness of solar products through various programs lead to significant interest in solar energy products among people which may increase willingness to pay.

Author contribution

Conception and design of study: Rohit Sharma, Praveen Kumar, Jayendran Venkateswaran, Chetan Singh Solanki; Acquisition of data: Rohit Sharma, Deepak Choudhary; Analysis and/or interpretation of data: Rohit Sharma, Deepak Choudhary; **Drafting the manuscript:** Rohit Sharma, Praveen Kumar, Sayli Shiradkar; Revising the manuscript critically for important intellectual content: Rohit Sharma, Sayli Shiradkar, Praveen Kumar, Jayendran Venkateswaran, Gautam N. Yadama; **Approval of the version of the manuscript to be published (the**

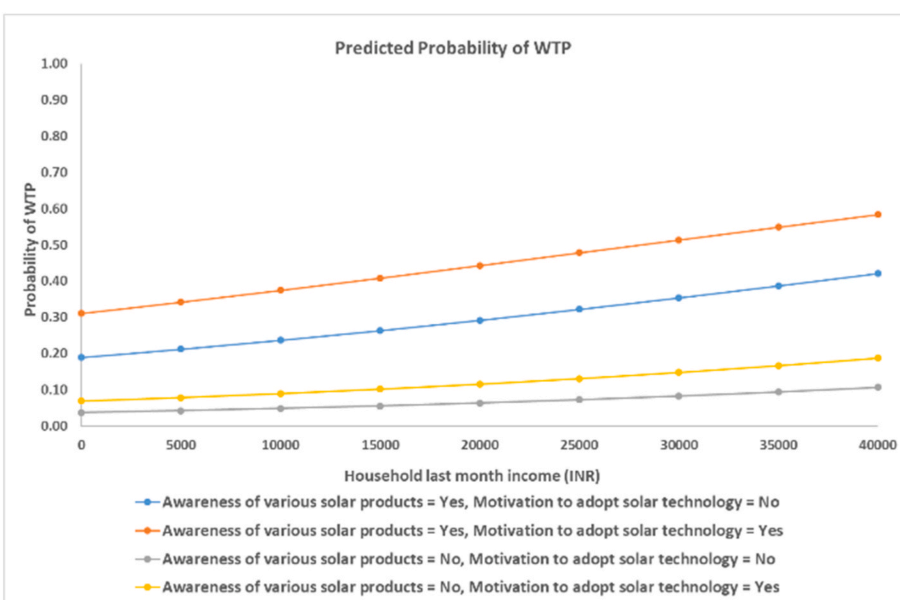

Fig. 3. Effect of Affordability on WTP moderated by awareness and motivation.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A.1 Descriptive statistics for household's motivation to adopt solar technology.

Motivations	Baseline	Follow up 1	Follow up 2	Endline
Solar products (SPs) are of good quality	3.8	4.2	4.4	4.6
Provide more time for activities during dark hours	3.8	4.2	4.4	4.5
Children use SPs for study	3.7	4.1	4.2	4.6
Satisfied with prior experience using SPs	2.8	3.1	3.3	3.9
Variety of SPs are available in the market	3.4	4.0	3.5	4.2
Access to credit for SPs	2.6	2.8	2.6	3.4
SPs are affordable	3.0	2.9	2.9	3.8
SPs provide light during frequent power outages	3.7	4.4	4.0	4.3
Reduced kerosene quota	3.2	3.6	3.3	3.8
Reduced Kerosene Subsidy	3.1	3.3	3.2	3.7
Family and friends like SPs	3.5	4.3	4.0	4.4
SPs have no adverse impact on health	3.7	4.4	4.2	4.6
SPs provide safety	3.7	4.4	4.2	4.5

Note: Scores are evaluated based on 5-point Likert scale: Strongly agree (5), Agree (4), Neutral (3), Disagree (2), and Strongly disagree (1), and the score is then calculated as a weighted average.

Appendix B

Table B.1 Descriptive statistics for awareness of various solar products.

Solar Products	Baseline		Follow up 1		Follow up 2		Endline	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Solar lantern	0.21	0.41	0.77	0.42	0.85	0.35	0.97	0.18
Solar Home System	0.01	0.09	0.07	0.26	0.08	0.28	0.24	0.43
Solar Mobile Charger	0.02	0.14	0.19	0.39	0.24	0.43	0.60	0.49
Solar Water Pump	0.01	0.09	0.04	0.19	0.06	0.23	0.26	0.44

Notes: The count gives the proportion of respondents who answered "Yes", and the score is then calculated as a weighted average.

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