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Do solar study lamps help children study at night? Evidence from rural India

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ABSTRACT

Lack of adequate and consistent lighting has a detrimental impact on the overall well-being of poor households in India. For school-going children in these households, this challenge has contributed to issues such as difficulty in studying after dark, reduced performance in schools, increased dropout from school due to poor educational outcomes, and exposure to pernicious emissions from predominantly kerosene-burning wick lamps. Use of off-grid solar lamps in these poor households has the potential to address these challenges. There is limited research investigating the impact of solar lamps on school going children in rural India. We analyzed the data collected from the Million Solar Urja Lamp Program (MSP) implemented in four states of India. The survey of 873 rural poor households in the states of Madhya Pradesh, Maharashtra, Rajasthan, and Odisha utilized a purposive random sampling method to reveal that the use of solar lamps increased total study time (TST) per day during dark hours from 88 to 118 min in the impact period. Furthermore, enhancement in study time was found more for girls (32 min/day) than boys (27 min/day). Total kerosene expenditures in these households decreased from 0.94 US$ to 0.67 US$ per month while total electricity expenditures dropped from 3.7 US$ to 3.5 US$ per month. The findings shows that number of rooms, household head's education, and the child's class have a positive and significant influence on TST in dark hours at home. A notable observation was that the use of kerosene-burning lighting during the impact period shows a negative correlation with TST in dark hours as compared to baseline period due to the adoption of solar study lamps. The results also show that with increment in studying time, a large number of children moved from lower study time group to moderate and higher study time group.

Introduction

The 21st century has witnessed remarkable advancements in science and technology that have included missions to Mars, the innovation of 4G, and cloud computing. Nevertheless, the grievous condition of electricity supply in India persists as 239 million people without basic electricity, with 231 million of them living in rural areas (E. Access, 2017; OECD/IEA, 2017), see Fig. 1. Due to high grid extension cost and high transmission losses in remote rural areas, many poor rural households are not connected to the national grid electricity network as they are incapable of paying the higher cost of electricity incurred in more remote regions (Nouni, Mullick, & Kandpal, 2009). In most states of India, rural areas suffer from load shedding of 12–14 h a day. The absence of electricity for such a long time span significantly affects the life of school-going children. When there is no electricity access, children either don't study at all or study under a kerosene oil lamp. Children's educational performance is hampered by the absence of electricity, and kerosene lamps emit carbon monoxide which adversely affects their health.

Today, approximately 69 million children[1] in India rely on dirty fuels especially kerosene, as a main lighting source. Moreover, the cost per unit of useful lighting energy services for kerosene-based lighting is up to 150 times greater compared to premium efficiency fluorescent lighting (Nouni et al., 2009). In addition usage of kerosene oil as a lighting and cooking fuel also results in household air pollution which harms women's and children's health (Chaurey & Kandpal, 2009). As conventional energy sources fall short, such rural households need decentralized, affordable, reliable, and clean energy solutions to meet their growing demands.

Portable solar lighting devices, e.g. solar lamps or solar lanterns have garnered attention as a promising affordable lighting source for

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[1] The International Energy Agency (2017) documented that in India there are around 239 million people without basic electricity. According to the Indian population composition, about 28.6% of the entire population are aged under 14, a quick estimation would give approximately 69 million. Because all of the children don't go to school, that's why the children who really study at night would be lesser in number than 69 million.

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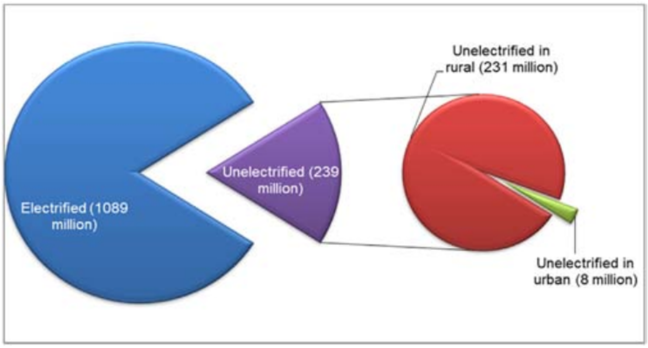

Fig. 1. Electrification in India in terms of population.

basic household needs in remote regions (Lighting Africa, 2010; Lay, Ondraczek, & Stoever, 2013; Smith & Urpelainen, 2014). As well, the United Nations, via its Sustainable Energy for All (SE4ALL) initiative and Sustainable Development Goal 7 (SDG 7), promotes the use of decentralized solar solutions to sustainably fulfill the universal energy access target for 2030 (Banerjee et al., 2013). Rural households that lack grid network access or are underprivileged by adequate/consistent electricity, stand to gain from solar-based electricity generation. Solar energy-based products can transmit light in a wider range from stand-alone solar lamps, with lamps only delivering 1–1.5 W_p and solar home lighting systems able to deliver electricity from 20 to 100 W_p. Portable solar lamps are the quick and affordable solution for the rural household deprived of basic lighting (Yoon, Urpelainen, & Kandlikar, 2014).

Most studies showed that home study after school improves children's knowledge retention (Stinebrickner & Stinebrickner, 2008; Dufur, Parcel, & Troutman, 2013). Alstone et al. suggested that insufficient nighttime lighting or unreliable and dim lighting may account for children's reduced performance on examinations (Alstone, Jacobson, & Mills, 2012). Furthermore, children who use kerosene and biomass fuel for studying purposes report eye strain and fatigue due to poor lighting conditions (Mills, 2016). Esper et al. discovered that children who utilized portable solar lights increased their study hours and enhanced their educational achievement (Esper, London, & Kanchwala, 2013). Furukawa et al. reported that by using the brighter, cleaner, safer, and zero-marginal-cost light of solar lamps, children were able to increase their study time by approximately 30 min per day (Furukawa, 2014). However, according to this study, solar lamps likely have an insignificant impact on educational attainment. This result is consistent with the findings of Kudo et al. that solar lanterns increased children's study hours at home, particularly at night and before exams, but saw no improvement in their academic performance (Kudo, Shonchoy, & Takahashi, 2017). Aklin et al. found that basic electricity access increased by 0.99 to 1.42 daily hours and found no systematic confirmation for changes in savings, spending, business creation, time spent working, or other more extensive indicators of socio-economic advancement (Aklin, Bayer, Harish, & Urpelainen, 2017). Kudo et al. also found that households who received either three solar lanterns or one solar lantern decreased their kerosene expense by approximately 75% and 50% respectively as compared with households who didn't have any solar lantern (Kudo et al., 2017). They also found students who received solar lanterns had considerably brought down the problems like eye irritation and redness. Recurrence of burn-injuries was also less likely for user's who received a bunch of solar products. This study was however consistent with Furukawa (2014), as they also showed that solar lanterns have an impact on children's health. Nandasena et al. suggested that improving the house indoor atmosphere conditions through solar lantern dissemination may have a confined effect on the health of children unless other hazards are addressed simultaneously (Nandasena, 2013).

Table 1
Demographic characteristics of study area.

State	Block	No. of villages (uninhabited + inhabited)	No. of surveyed HH	ST population (%)-rural	ST population (%)-urban
Maharashtra	Trimbak	125	306	83.63	35.78
Odisha	Jharigam	112	96	62.03	–
Madya Pradesh	Beohari	153	220	44.18	14.64
Rajasthan	Ghari	208	251	60.01	21.12

This research investigates the effect of solar study lamp (also called Pico-Photovoltaic or Portable Solar Lighting) distribution on school-going children's studying behavior in dark hours at night. Through a purposive random sampling (PRS) we investigated the impact of basic electricity access through the distribution of solar study lamps in rural Indian households. The solar study lamp kit at the subsidized price of 120 INR (~1.79 US$)[2] was given to 1 million rural school-going children enrolled between 5th–12th classes in the four Indian states of Madhya Pradesh, Maharashtra, Rajasthan, and Odisha. The market price of the solar study lamp is 500 INR (~7.46 US$).

We investigated the effects of the solar study lamp on various types of outcomes: children's study hours, expenditures on energy, and kerosene consumption at the household level. The extent of the lamp's effects depended on the usage behavior of the children and their households. Has the solar study lamp been used by the children as a replacement for kerosene lamps or simply used as an additional light? Which members of household use the solar study lamp and for what purpose? Do households extend their activities that need lighting into the night hours, or do they simply move their daytime activities to the evening time?

This study is closely related to Kudo et al. (2017), Aklin et al. (2017), Grimm, Munyehirwe, Peters, and Sievert (2017), Hassan and Lucchino (2016), and Furukawa (2014), wherein randomized control trials were performed to examine the impact of Pico-PV technology on academic performance of children and the benefits of replacing kerosene lamps with solar lamps in rural areas. The sample size of Kudo et al. (2017) and Aklin et al. (2017) was 882 in Chars, Bangladesh and 1281 in Barabanki, India respectively. The other studies suffered from low statistical power due to limited sample sizes: 300 in Rwanda (Grimm et al., 2017), 341 in Kenya (Hassan & Lucchino, 2016), and 155 in Uganda (Furukawa, 2014). The present investigation furthers these previous studies by disseminating solar study lamps that are more affordable and adaptable than those utilized in past investigations. Until now, lack of literature exists on the take-up and effects of solar lamps or lanterns on children's lives especially in rural households in India. As per the authors' knowledge, the only published investigations are Kudo et al. (2017) and Furukawa (2014), which focus on children's study hours and their educational outcome.

A descriptive analysis of the impacts of solar study lamp on children study time per day during dark hours, expenditure on kerosene and electricity consumption has been reported in our previous work (Sharma, Deepak, Arora, Venkateswaran, & Solanki, 2018). This manuscript is an extension of the work done (Sharma et al., 2018). In this paper, the ordinary least squares (OLS) regression was conducted on the same datasets to exhibit the relationship between the dependent variable (i.e., Total study time) & the different independent variables. We further analyzed the clustered data based on K-Means clustering analysis, to know how much extra study time was spent by various groups after they received the lamps, and how was the movement of children into the clusters based on total study time? Demographic characteristics of the study area, detailed about solar study lamp and its working principle are also described in the paper. Our results evidenced the factors influencing the total study time of children associated with

[2] Assuming 67 INR is approximately 1 US$.

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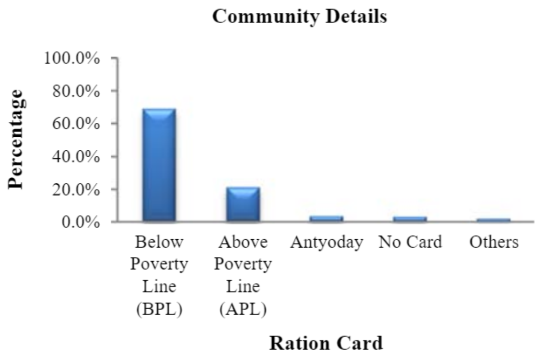

Fig. 2. Community details on the basis of ration card.

the solar study lamp. The movement of children in different clusters from the baseline to the impact period indicates that solar study lamps helped children to study more. Systematic large-scale studies aimed at understanding the impact of solar lamps are still scarce. This investigation intends to fill this knowledge gap by thoroughly assessing the impact of solar study lamps on the life of rural households, especially school-going children.

This article is organized as follows: the Survey and experimental design section gives the background study, solar lamp and its working principle, sampling procedure, and survey design. The third section presents all results. The fourth section provides the conclusion.

Survey and experimental design

Background

We chose to implement our project of distributing 1 million solar lamps to school- going children in rural areas in the four Indian states (Maharashtra, Madhya Pradesh, Odisha, and Rajasthan) with the lowest rates of electrification. With the support of 9 institutional partners the project covered over 10,000 plus villages. This included 21 districts in total (2 in Odisha, 8 in Rajasthan, 2 in Maharashtra, and 9 in Madhya Pradesh) and 72 blocks (19 in Odisha, 15 in Rajasthan, 8 in Maharashtra, and 30 in Madhya Pradesh) with a 75% saturation target in each block.

We conducted our study in rural villages located in four blocks: Beohari, Trimbak, Ghari, and Jharigam located in the state of Madhya Pradesh, Maharashtra, Rajasthan, and Odisha respectively. Demographic characteristics of the study area as per the 2011 Census of India are given in Table 1. These villages have a low electrification rate and a predominantly tribal population. As hardly any alternative sources of energy exist in these villages, most of the residents use kerosene oil as their primary energy source e.g. lighting, cooking, studying, and other activities.

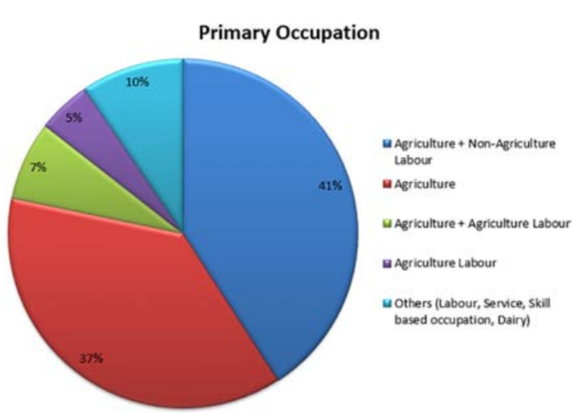

Fig. 3. Primary Occupation of the household.

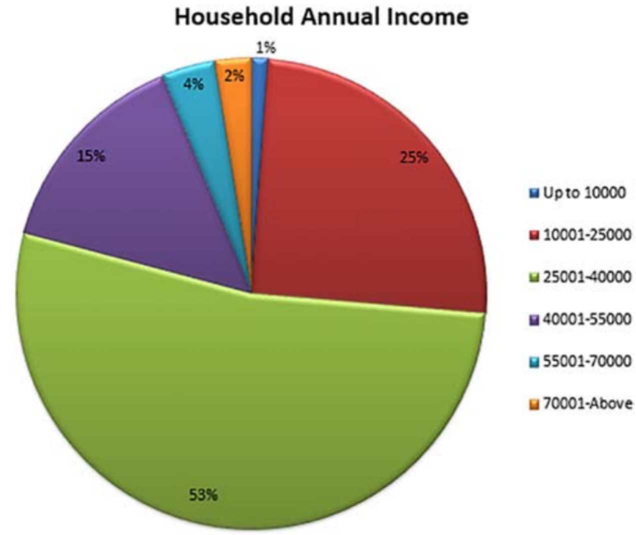

Fig. 4. Household income per annum.

Some households used battery-powered flashlights for emergencies, but these flashlights have very limited power to perform tasks. The total sample households surveyed for baseline and impact were 873.

69.3% of the survey respondents were below the poverty line[3] and 3.8% of the respondents were in the poorest of the poor category (see Fig. 2). The main occupation of the respondents were Agriculture & Non-Agriculture labours (41%) and Agriculture (37%) (see Fig. 3). Interestingly, 74% of households had an annual income of >30,000 INR or ~448 US$ (see Fig. 4) which contradicts with the community details based on ration card (see Fig. 2) and with the definition of below poverty line. This might be because the households whose annual income was above 27,000 INR (~403 US$) were still receiving the benefits of Antyoday and the BPL ration card.

Solar study lamp

The solar lamp designed and distributed for the Million Solar Urja Lamp Program (MSP) is accredited by the Central Power Research Institute and the Electronics Test & Development Centre, both located in Bangalore. Four types of collaborators were identified in the MSP. These included financial institutions that funded the project, vendors who provided the lamps in a disassembled form, academia that conducted evaluations and surveys at different phases to track the program's progress, and the Institutional Partners (IPs) which were NGOs with a strong local presence.

The solar lamp distributed in the project is a standalone PV system designed as a study lamp for school-going children in rural areas (see Fig. 5). It contains a load LED, a battery, a controller, and a solar module. The lamp has a flat base of 10 cm × 10 cm to ensure optimum stability. The connecting wire for the LED passes from the base of the lamp through the flexible neck which can be adjusted to different heights. The height between the base and LED head is about 1.0 ft. The head is designed to ensure that the light intensity is at least 250 lx, which, by international standards, is sufficient for reading. Here we consider here the workbook area to be 2 ft × 1 ft (0.185 $\mathbf{m^2}$). The LED used in the solar lamp has a luminous efficiency of 150 Lumens/Watts. The solar lamp can be operated in two modes (modes 1 and 2) (see Table 2). Mode 1 requires 0.192 W of power and mode 2 requires 0.352 W of power. The lux level (Lumen/$\mathbf{m^2}$) for Mode 1 and Mode 2 can be calculated at 155 lx and 285 lx respectively. Mode 1 can be used for general

[3] The income limit of the families below poverty line is around 27,000 INR per annum. Jan 23, 2016 (https://digitalindia.gov.in/content/below-poverty-line-certificate).

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Fig. 5. Solar study lamp.

Table 2
Operating modes of solar study lamp.

Mode	Power (W)	LED (Lumen/Watt)	Lumen	Area (m^2)	Lux (Lumen/m^2)
1	0.192	150	28.8	0.185	155
2	0.352	150	52.8	0.185	285

purposes and mode 2 for study purposes. When fully charged, the lamp delivers 150–250 lx light on its full intensity mode for approximately 5 h and 8 h on low intensity mode, thereby meeting the international standards for domestic lighting (DiLaura, Houser, Mistirck, & Steffy, 2011).

Working principle of solar study lamp

Solar panels are made up of many solar or photovoltaic cells that convert light energy into electricity through the photovoltaic effect (Solanki, 2015). There are a total of 10 solar cells in a solar panel which are generally made up of poly-crystalline silicon. A solar lamp includes a solar panel, a printed circuit board (PCB), one rechargeable battery, a load wire and a light emitting diode (LED) (see Fig. 6). Solar study lamps usually operate at a rated voltage of 3.2 V direct current (DC). The solar panel is usually placed in the sunlight to collect maximum energy from the sun. This energy is stored in the lithium iron phosphate (LiFePO4) battery with the help of the PCB circuit. This stored electrical energy is used to light up the LED whenever required. The microcontroller on the PCB makes sure that the light intensity from the LED is constant, irrespective of the Battery voltage. As a result, the LED gives the same light intensity consistently both when it is fully charged and on low battery. The PCB also protects the battery and LED from various faults such as short-circuiting. The LiFePO4 battery typically has a backup of 5–8 h per day.

Sampling procedure

We used a "purposive random sampling" method to select the sample for the household survey. The sampling plan comprised of two phases: purposive sampling followed by random sampling. For purposive sampling, we choose one block in each of the four states where the Million Solar Urja Lamp Program (MSP) had been implemented. The second phase of sampling involved dividing the population into strata, determining their proportion, and then taking a sample through random sampling. The two strata for this sampling were the electrification status and the caste category of the households. The castes were divided into three categories, namely, Scheduled Castes (SC), Scheduled Tribes (ST), and others (which includes "General" and "Other Backward Castes" (OBC)). The sample (number of households to be surveyed) was developed through the 2011 Census block level data which helped to determine the proportionate percentage of electrified and non-electrified households and their caste composition.

Experiment and survey

The survey was conducted in two phases in one block in each four states. A Baseline survey was administered before the intervention, followed by an Impact survey administered after the intervention. The Baseline and Impact survey were conducted in December 2015–February 2016 and October 2016–December 2016 respectively (see Table 3). We acquired extensive data at the household level to comprehend the social and economic conditions of the school going children and their households. The data includes information on household

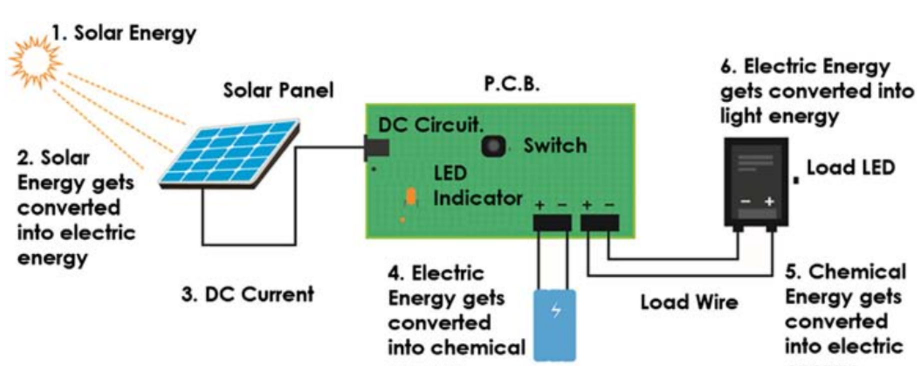

Fig. 6. Working principle of solar study lamp.

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Table 3
Time span for surveys.

Location	Baseline	Impact
Beohari, Madya Pradesh	Dec 2015–Jan 2016	Dec 2016
Trimbak, Maharashtra	Jan 2016–Mar 2016	Oct 2016–Dec 2016
Jharigam, Odisha	Jan 2016–Feb 2016	Oct 2016–Nov 2016
Garhi, Rajasthan	Dec 2015–Jan 2016	Dec 2016

background, children's activity in the household, kerosene consumption, electricity consumption, and details about electric devices utilized.

Results

This section examines the impacts of solar study lamps on students' study hours, kerosene consumption, and expenditures on electricity. The descriptive statistics for baseline and impact are illustrated in Table 4. Our calculations reveal that, on average, during a nine-month period, the amount of time students used for home study during dark hours increased by 0.49 h (~30 min) as shown in Fig. 7.

The net impact of solar study lamps on study time at home was found to be statistically noteworthy and positive. Moreover, girls' study time during the baseline period was less when compared to boys, but after adoption of the lamps the girls' study time increased by 0.54 h per day (~32 min per day) as compared to 0.45 h per day for boys (~27 min per day) as shown in Fig. 7. The significant reduction in total kerosene expenditure between baseline and impact, as shown in Fig. 8, added to a reduction in the total expenditure of beneficiary households by 28.3%. The decrease in monthly kerosene expenditure corresponds to approximately 18 INR per household (~0.26 US$). As can be clearly seen from the results, households that received lamps reduced their kerosene expenditure for lighting purposes by approximately 39%. A decrease in kerosene usage for lighting might have led to a reduction in household air pollution with potential effects on children's' health. However, kerosene expenditure for cooking increased because of variations in climate conditions, particularly when the temperature changed from the summer to the winter season. Total electricity expenditure, as shown in Fig. 8, decreased by approximately 5.8% corresponding to approximately 15 INR per household (~0.22 US$). Number of observation for total electricity expense is different for impact survey (see Table 4) because the number of grid-connected households increased during the nine-month period.

Regression analysis

To exhibit the relationship between the total study time (i.e., dependent variable) and the different independent variables, an ordinary least square linear regression analysis was conducted. Table 5 presents the regression results for the solar study lamp's effects on total study time in both the baseline and impact periods. The independent variables are number of rooms, household size, education of head of household, child class (i.e., education level), kerosene used for lighting, student gender, and type of card.

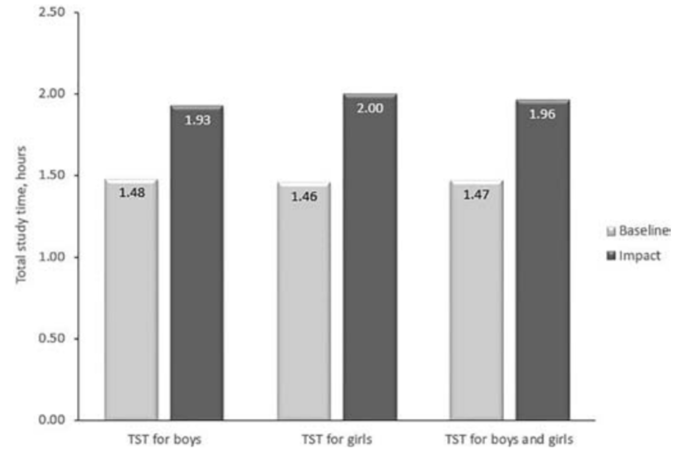

Fig. 7. Plot of total study time in hours.

$$\begin{aligned}\text{Total Study Time (TST)} = \alpha &+ \beta1 \text{ Number of Rooms} \\ &+ \beta2 \text{ Household Size} \\ &+ \beta3 \text{ Below or up to class 4} \\ &+ \beta4 \text{ Class 5 to class 8} \\ &+ \beta5 \text{ Class 9 to class 10} \\ &+ \beta6 \text{ Class 11 to class 12} + \beta7 \text{ College} \\ &+ \beta8 \text{ Child class} \\ &+ \beta9 \text{ Kerosene used for lighting} \\ &+ \beta10 \text{ student gender} + \beta11 \text{ Type of card} \\ &+ \varepsilon\end{aligned}$$

where TST is the dependent variable, β are the coefficients and ε represents a stochastic error term.

The factors that influenced the total study time in dark hours in the baseline period were number of rooms, child class, and kerosene used for lighting purposes (see Table 5, Column 1&3). Number of rooms has a significant and positive correlation with TST, meaning that a greater number of rooms were associated with children studying more. More rooms in a house can help children to study for longer periods time because children will have more space to study in peace. Results provide a positive and significant association between children's class and TST. Children's in higher classes devote more time to studying because they are preparing for their careers as opposed to children in small classes. Kerosene used for lighting also shows a positive and significant correlation with TST in the baseline because the respondents had fewer energy options and relied on kerosene as fuel for studying purposes. There was a negative coefficient for household size with TST, but it was not significant. Children have trouble studying for long periods of time in larger families because these households may lack the resources

Table 4
Baseline and impact descriptive statistics.

Variable	Baseline			Impact			Mean difference (impact-baseline)	*t*-Test (baseline vs. impact p-values)
	Mean	Std.	Observations (N)	Mean	Std.	Observations (N)		
Total study time in dark hours (hours)	1.47	0.65	873	1.96	0.84	873	0.49	<0.0001
Total study time for boys (hours)	1.48	0.68	456	1.93	0.83	456	0.45	<0.0001
Total study time for girls (hours)	1.46	0.63	417	2	0.85	417	0.54	<0.0001
Kerosene spending-pds (US$/month)	0.77	0.36	873	0.58	0.41	873	−0.19	<0.0001
Kerosene spending-private shop (US$/month)	0.17	0.46	873	0.09	0.49	873	−0.07	<0.0001
Total kerosene expenditure (US$/month)	0.93	0.49	873	0.67	0.64	873	−0.26	<0.0001
Kerosene used for lighting (US$/month)	0.84	0.51	873	0.51	0.48	873	−0.32	<0.0001
Kerosene used for cooking (US$/month)	0.08	0.15	873	0.11	0.20	873	0.03	<0.01
Total electricity bill (US$/month)	3.73	2.60	413	3.51	2.91	492	−0.22	–

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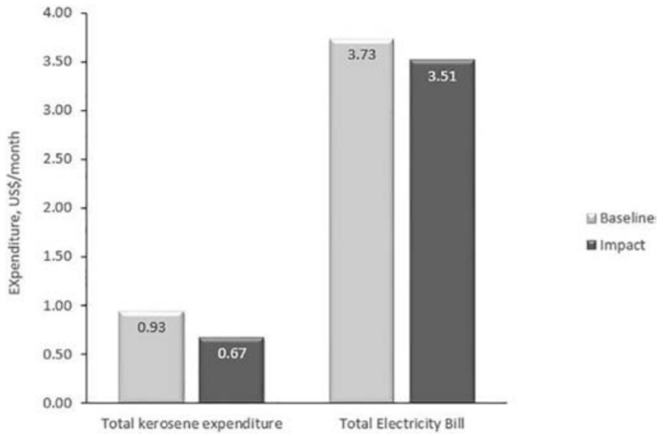

Fig. 8. Plot of total expenditure on kerosene and electricity.

or space for children to study in peace during night hours. The results also show a positive relationship between head of household education and TST. Educated heads of household can better motivate their children to study and help them complete their homework during the nighttime. As the level of household head education increases, the coefficient increases (see Table 5, Column 1). User's gender (i.e. Female child) shows a negative but insignificant correlation with TST, meaning that girls spend less time studying than boys. Girls are more involved in domestic work in the home which causes them to study less as compared to boys. Families possessing BPL and Antyoday cards are negatively associated with the TST.

The estimates for the regression model in the impact period show some changes in the coefficients and significance level of the independent variables with the dependent variable (see Table 5, Column 4&6). Number of rooms and child class in the baseline period is positively and significantly correlated with the TST. A notable observation is that the kerosene used for lighting in the impact period shows a negative but not significant correlation with TST as compared to the baseline period. This was expected because the good quality of light from the solar study lamp and the surplus lighting time it provided helped children to study more at home under better conditions, as shown in Fig. 9. It means people with dependence on kerosene for lighting their houses tend to look out other options for lighting. Also, female children in the impact period show a positive correlation with TST. We estimate that the total study time for the girl students who received the solar lamp will be higher as compared to boy students. A relationship between the user's gender and usage of the solar lamp for studying purposes does not exist in the existing literature. In the Impact period, our findings show strong evidences of a significant and negative relationship between children belonging to families who possess BPL and Antyoday cards and TST. Children who belong to families above the poverty line (APL) or APL card holding families may study more because higher income households are able to provide more facilities and a better environment for studying as compared to Antyoday card holding and below poverty line (BPL) families.

Cluster analysis

In an additional analysis, children were clustered into three groups based on higher, moderate and lower total study time for both baseline and impact using K-Means cluster analysis (Everitt, 2011). This analysis separates the observations into several different clusters in which each observation belongs to the cluster with the nearest mean served as a basis of the cluster. The result of this clustering is presented in Table 6. Three sets of measurements are given: one for cluster 1 which represents higher study time (181–370 min), second for moderate study time (91–180 min) and a third for lower study time (0–90 min). From the outcomes of this clustering, the characteristics of each cluster/group have been analyzed against a baseline.

From the results of cluster analysis as shown in Fig. 10, we found the majority of children from our sample falls in cluster 3 (i.e. 59%) which represents the largest number of children studied less during dark night hours whereas only 1% of the student population falls under cluster 1 which represents the maximum time for study at a baseline. Our finding shows that the intervention leads to a 28% decrease in cluster 3 as compared to baseline whereas clusters 1 and 2 increased by 5% and 23%, respectively. That implies a significant movement into the clusters associated with higher study time after the distribution of lamps.

To know how much extra study time was spent by children in various groups, we further analyzed the clustered data on the basis of how much studying each group did before having the lamps. The left and right side of Table 7 shows the movement of children based on total study time and mean difference of TST into the clusters. Our results reveal that the effect of solar study lamp on children was significant, the majority of children moved from cluster 3 (59%) to cluster 2 (33.4%) and cluster 1 (2%) with increment in studying time of 1.18 and 3.1 h respectively, and from cluster 2 (40%) to cluster 1 (3.6%) with enhancement of studying time of 1.92 h. Around 53% of children

Table 5
Ordinary least squares (OLS) regression analysis on baseline and impact periods for total study time of children in dark hours dependent variable: total study time of children, N = 873.

	Baseline			Impact		
	1	2	3	4	5	6
	Coefficient (95% CI)	Std error	p value	Coefficient (95% CI)	Std error	p value
Predictor variables						
Number of rooms	4.33 (2.17–6.50)	1.10	<0.0001	6.37 (3.62–9.12)	1.40	<0.0001
Household size	−0.37 (−1.59–0.85)	0.62	0.55	−0.62 (−2.46–1.22)	0.94	0.51
Head of household education (vs none)						
Below or up to class 4	−1.25 (−8.92–6.42)	3.91	0.75	2.88 (−7.83–13.59)	5.46	0.60
Class 5 to class 8	3.11 (−2.80–9.02)	3.01	0.30	7.21 (−1.01–15.43)	4.19	0.09
Class 9 to class 10	5.79 (−1.29–12.87)	3.61	0.11	4.69 (−5.08–14.47)	4.98	0.35
Class 11 to class 12	11.90 (2.35–21.45)	4.87	0.01	13.17 (−0.03–26.38)	6.73	0.05
College	14.96 (−1.57–31.49)	8.42	0.08	17.01 (−5.97–39.98)	11.71	0.15
Child class	8.70 (7.55–9.85)	0.59	<0.0001	6.74 (5.14–8.35)	0.82	<0.0001
Kerosene used for lighting (INR)	0.11 (0.04–0.18)	0.04	<0.01	−0.02 (−0.13–0.08)	0.05	0.66
Female child (vs male child)	−1.92 (−6.58–2.74)	2.37	0.42	4.02 (−2.43–10.48)	3.29	0.22
BPL (vs APL)	−3.52 (−8.75–1.71)	2.67	0.19	−7.34 (−14.70–0.03)	3.75	0.05
Adjusted R square	0.234			0.117		
No. of observation	873			873		
Log likelihood	−4609.00			−4323.99		
AIC	8673.98			9244.01		

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Fig. 9. Children studying under kerosene light (left) and solar study lamps light (right).

Table 6
K-means cluster analysis of total study time.

Cluster	Range (TST in minutes)	Baseline		Endline	
		Cluster center	No. of observations	Cluster center	No. of observations
1 (Higher study time)	181–370	240	8	245.5	51
2 (Moderate study time)	91–180	127.5	350	133.7	553
3 (Lower study time)	0–90	59.2	515	61	269
		Total	873	Total	873

remained in the same cluster after the intervention of solar study lamp. However, the enhancement of 1.08, 0.13 and 0.05 h for N = 2, 256, and 206 were noted in cluster 1, 2, and 3 respectively during the impact period. As shown in the right side of Table 7 with numbers in red color, only 8% of children moved to cluster 3 (i.e., children studied less) from cluster 2 and 1 after receiving the lamps. These results show that solar study lamps tend to help children to enhance their study time.

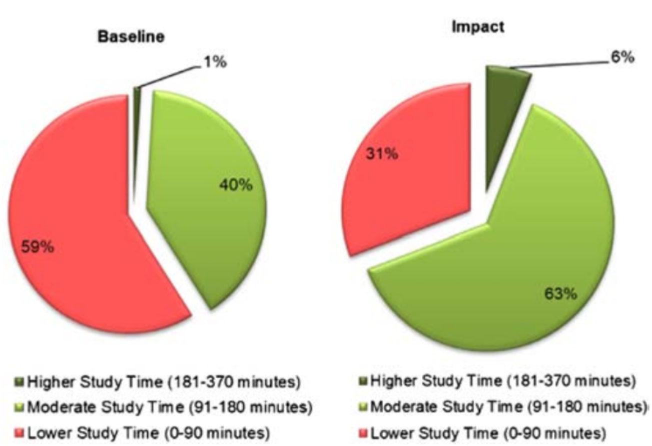

Fig. 10. Cluster wise percentage change of children population in baseline and impact.

Conclusion

Our experimental findings indicate that solar study lamps, in fact, lead to improvements in the life of rural households. Lighting is limited in these energy-poor rural areas and the solar study lamp was used extensively by the beneficiaries. The most significant finding of our study is that the adoption of solar study lamp increased total study time of children during dark hours by approximately 0.49 h/day (~30 min/day). Besides, this enhancement was more significant for girls (0.54 h/day or 32 min/day) than for boys (0.45 h/day or 27 min/day). Our regression results indicate that study in dark hours depends on various factors which influence the total study time for children. The number of rooms in the household and child class has a significant positive association with the total study time in dark hours. The household head's education level also has an impact in motivating their children to study as well as helping them to complete their homework during night time. In the impact period, good quality of lighting and surplus lighting time from solar study lamps helped children to replace kerosene lamps and study more at home under better conditions. It means people with a dependence on kerosene are ready for other options for light. K-mean cluster analysis based on total study

Table 7
Movement of children and mean difference of TST into the clusters. Green color represents increment and red color represents decrement in TST.

Movement of children based on TST into the clusters (N = 873) — Left

Impact \ Baseline	Cluster 1	Cluster 2	Cluster 3
Cluster 1 (Higher Study Time)	2	32	17
Cluster 2 (Moderate Study Time)	5	256	292
Cluster 3 (Lower Study Time)	1	62	206

Mean difference of TST into the clusters (Hours/day) — Right

Impact \ Baseline	Cluster 1	Cluster 2	Cluster 3
Cluster 1 (Higher Study Time)	1.08	1.92*	3.1***
Cluster 2 (Moderate Study Time)	−1.60	0.13***	1.18***
Cluster 3 (Lower Study Time)	−3.00	−1.06	0.05**

***Denote significance at $p < 0.0001$, ** at $p < 0.001$, and * at $p < 0.01$.

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time shows that a significant number of children moved from lower study cluster to moderate and higher study cluster during impact period. With enhancement in studying time, almost 53% of children remained in the same cluster during the baseline and impact period, and 39% of children moved to moderate study cluster and higher study cluster. Merely 8% of children moved to lower study cluster after receiving the lamps. These results show that the beneficiaries replaced the kerosene lamps with solar lighting instead of just augmenting their energy consumption. The study opens avenues for further interrelated investigation on whether the increase in study hours leads to better educational outcomes and student retention in schools.

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