Impact of Solar Off-grid Lighting Solutions on Rural Households in the states of Uttar Pradesh and Bihar in India

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Contents

List of Figures

List of Tables

Terms and Abbreviations

TERMS/ABBREVIATIONS	DESCRIPTION
Grid-connected households	Households with Electricity connectivity
Off-grid households	Households without Electricity connectivity
Off-grid, battery-based lighting devices	Devices like emergency lamps or torches or flashlights that use batteries
Traditional lighting devices	Kerosene lamps with or without glass enclosure, candles
CFL	Compact Fluorescent Lamp
HH	Household
HSC	Higher Secondary Certificate (Class 12)
LPG	Liquefied Petroleum Gas (cooking gas used in homes)
NGO	Non-Governmental Organization
PDS	Public Distribution System
SSC	Secondary School Certificate (Class 10)
USD	United States Dollar
INR	Indian Rupee
mAh	Milliampere Hour

All monetary amounts are in Indian Rupee (INR) unless otherwise indicated.

Acknowledgements

This report has been prepared to share the key findings of a study undertaken by IFC's Lighting Asia/India Program to evaluates changes in the households' economic, health, and educational parameters, usage of traditional fuel based lighting, before and after the intervention of solar lanterns. The two-and-a-half year-long study, completed in 2016, involved an extensive, three-stage (baseline, midline, and endline) data-collection process. IFC is grateful to Kantar IMRB, India (Social Infra Group of the B2B&I Unit) for the research and field work. IFC also thanks d.light for partnering with the Lighting Asia/India Program for the analytical phase of this impact assessment study. The study reflects the views of IFC and does not necessarily reflect the views of the Government of India and the findings of the study are not binding on the Government of India.

This study was led by Anjali Garg and Brendon Mendonca of IFC's Lighting Asia/India Program. This study benefited substantially from the constructive advice and feedback from many staff at IFC: Jun Zhang (Country Head, India), Vikramjit Singh (Senior Country Officer, India), Russell Sturm (Principal Operations Officer), Arthur Itotia Njagi (Senior Operations Officer), and Hemant Mandal (Senior Energy Specialist).

Executive Summary

Introduction

This document summarizes the key findings of an impact assessment study of the intervention of solar lanterns on rural households in the states of Bihar and Uttar Pradesh in India. The two-and-a-half year-long study, completed in 2016, involved an extensive, three-stage (baseline, midline, and endline) data-collection process. The study was undertaken by the Lighting Asia/India program with support from Kantar IMRB, India (Social Infra Group of the B2B&I Unit).

Households that participated were separated into two groups: treatment households, which acquired a solar lantern, and control households, which did not. The impact of the intervention was assessed by comparing the data measured across time, as well as across treatment and control groups.

Objectives

The main objectives of this study were to evaluate changes in the households' economic, health, and educational parameters, and to analyze their usage of traditional fuel-based lighting, before and after the intervention of solar lanterns.

Key Findings

Table 1 lists the key findings of the study. Overall, the intervention of solar lanterns had a significant positive impact on educational and economic parameters among the beneficiary households. There was a significant decline in the number of households using kerosene as the primary source of fuel for lighting, and an associated decrease in patterns of kerosene consumption.

Treatment households' dependency on kerosene for lighting reduced by 75 percent, from four hours per day to one hour. There was a concomitant reduction in fuel consumption by 1.28 liters per household per month. These households managed to save an average of INR 300 (USD 4.47) per year as a result, of which INR 265 (USD 3.95) were from the reduced use of kerosene and candles.

Table 1: Impact Parameters in Treatment Households at Baseline and Endline

Parameter	Baseline	Endline
HHs identifying kerosene as the primary light source	83%	24%
Kerosene lamp usage	4 hours	1 hour
Kerosene fuel consumption	3.12 liters/month	1.84 liters/month
Total number of hours of lighting available/HH/day	6.4 hours	8.1 hours (50 percent from solar device)
Total number of hours of study/HH/day	1 hour 44 min (75 percent from traditional devices)	2 hours 36 min (66 percent from solar device)

Image: International Finance Corporation

The intervention led to an increase of 26 percent in hours of lighting per day from 6.4 hours to 8.1 hours per household per day. Access to the solar lanterns also increased the average time children in treatment households spent studying, by nearly an hour a day compared to baseline. Children in control households continued to use primarily the traditional devices and off-grid devices, chiefly kerosene lamps, for studying. A single solar lantern, however, cannot satisfy the lighting needs of an entire household. Endline results show that the use of kerosene for lighting persists.

The overall perception of treatment households, as reported, was that the main benefits of solar lighting included a brighter light source, longer hours of study for children, and increased health and safety for family members. A significant number of these households also identified the solar lantern's portability and cost savings as key benefits. The solar lanterns were used predominantly in the kitchen and bedroom areas, and to a lesser degree in the hall-room and other areas of the dwelling.

Although the study focused on household activities and not productive-use applications, anecdotal evidence indicated that solar lanterns had a positive impact on productivity in home-based piecework, such as tailoring.

While examining the effect of this intervention on the health of the members of treatment households, the study sought to discover whether a reduced usage of kerosene lighting would result in a decreased incidence of breathing disorders or asthma. No direct correlation between the two was, however, captured during the timeframe of the research. No correlation was found, likewise, between reduced usage of kerosene-fuelled lighting devices and the incidence of fire accidents. Other studies have demonstrated that kerosene lighting has negative effects on human health and safety. [1]

[1]The following four studies have focused on the impact of kerosene-based lighting systems on health and safety: (1) Shapiro, Ruth, ed. 2012. The Real Problem Solvers: Social Entrepreneurs in America. Stanford: Stanford University Press. (2) Poppendieck, Dustin. 2010. 'Particulate Emissions from Kerosene Lanterns'. Paper prepared for Lighting Africa's 2nd International Business Conference and Trade Fair, Nairobi, May 18–20. https://www.lightingafrica.org/wp-content/uploads/2016/07/2010-Conference-Report-Updated.pdf. (3) Epstein M.B. et al. 2012. 'Household Fuels, Low Birth Weight, and Neonatal Death in India: The Separate Impacts of Biomass, Kerosene, and Coal'. International Journal of Hygiene and Environmental Health 216 (5): 523–32. (4) World Health Organization. 2014. 'Fact Sheet: Household Air Pollution and Health'. http://www.who.int/en/news-room/fact-sheets/detail/household-air-pollution-and-health

Introduction

As of September 2017, around 40 million rural households in India were un-electrified. State-wise, the greatest numbers of un-electrified households were in Uttar Pradesh and Bihar, at 15 million and 6 million, respectively[2]. In these states, many households that are connected to the grid also suffer from unreliable electricity supply. A sizeable number of these households, therefore, continue to rely heavily on kerosene for their lighting needs.

Not only does kerosene provide poor lighting, when used as a domestic fuel it has detrimental effects on health and the environment. Additionally, kerosene subsidies cost the GoI a significant amount every year. It is estimated that GoI currently provides a subsidy of around INR 600 (USD 9.5) per annum to each household using its allocation of PDS kerosene (IISD, 2017)[3]. This outlay can be greatly reduced with the use of solar lighting replacing the need for kerosene. In the last few years, off-grid, battery-based devices such as LED torches, rechargeable lamps, and solar lanterns have emerged as alternate lighting sources. Despite these newer solutions, kerosene lamps continue to be the primary domestic light source in areas that lack reliable electricity supply.

IFC's Lighting Asia/India program was initiated in 2012 to increase access to clean and affordable energy in rural regions that lack efficient electricity supply, by promoting the use of modern solar lighting products and systems. In its second phase, which began in September 2016, the program aims to increase access to clean and affordable energy in rural India by promoting modern, off-grid lighting products and systems. Implemented in partnership with Australia, Austria, Canada, Hungary, Iceland, Italy, Luxemburg, the Netherlands, and Norway, the program works with the private sector to remove market entry barriers, provide market intelligence, foster business-to-business linkages, and raise consumer awareness of modern lighting options.

The study, performed in the north Indian states of Uttar Pradesh and Bihar, was a longitudinal exercise with data inputs taken over a period of two years at three stages: baseline, midline, and endline. Data from treatment households (households that acquired solar lanterns) was then compared with data from the control group (households that did not acquire solar lanterns). For this analytical phase of the impact assessment IFC partnered with d.light, a company that provides solar-powered solutions for people without access to reliable electricity. The company aims at enhancing quality of life by providing affordable, environment-friendly, and quality-assured[4] solar energy solutions for households and small businesses.

The d.light solar lantern selected for this study, model S300, provides four to 17 hours of light depending upon the brightness setting used. It includes a mobile telephone charging point and is paired with a separate solar panel equipped with a handle for portability. The lantern's total light output ranges from 29 lumens (at the medium light setting) to 110 lumens (high setting), which makes it about 10 times brighter than a kerosene lamp. Its maximum power output is 1.6 watts and the battery capacity is 1800 mAh. The lantern comes with a two-year warranty, beginning from the date of purchase and, at the time of this study, was priced at INR 1,895 (USD 28.30).

d.light S300

[2]Data from the website of the Deendayal Upadhyaya Gram Jyoti Yojana, Government of India. Accessed September 30, 2017. http://www.ddugjy.gov.in/portal/index.jsp.

[3]Kerosene to Sustainable Lighting Solutions for Homes in Rural India: Achieving a transition from kerosene to off-grid solar for lighting, Richard Bridle and Kieran Clarke, IISD, August 2017

[4]https://www.lightingglobal.org/quality-assurance-program/our-standards/

Objectives of the Study

The study had two main objectives:

- To evaluate the extent of change in the lives of beneficiaries, using economic, health, and educational parameters.
- To analyze the impact on the usage of traditional, fuel-based lighting, before and after the introduction of solar lanterns, in the control and treatment households.

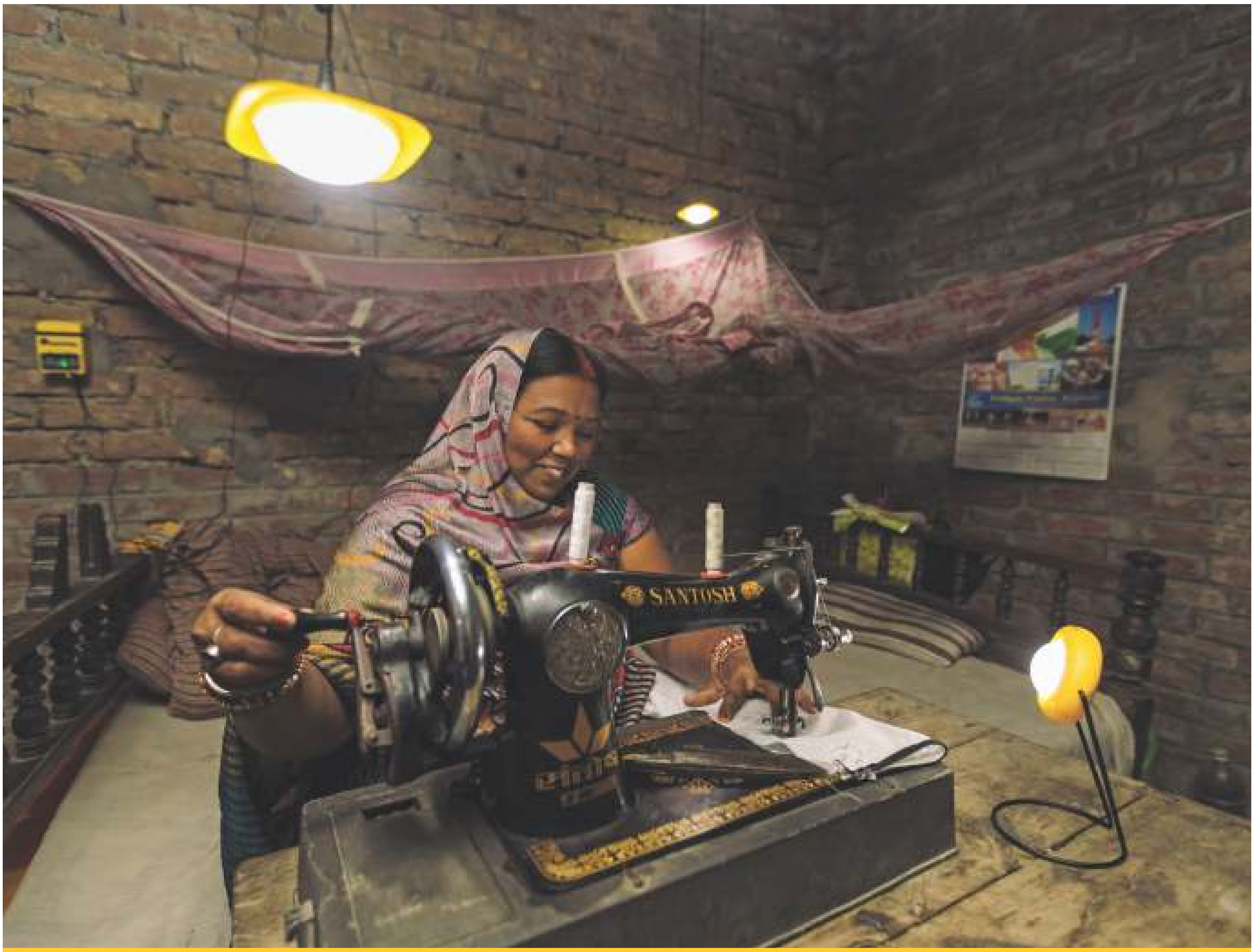


Image: greenlight planet

Methodology

This section describes the methodology of the survey, including design, data collection, location and household selection, impact parameters, and assessment methodology.

Evaluation Design

To accurately weigh the impact of the intervention, the study used a quasi-experimental design. Treatment and control households were selected in the same or neighbouring villages, and data collection was undertaken in three stages, as follows:

- Baseline survey, to assess the situation prior to the sale of the solar appliance; September 2014 to September 2015.
- Midline survey, to assess the situation after adoption of the solar appliance; April to June 2016.
- Endline survey, to assess the long-term usage and impact of the adoption of the solar appliance; November to December 2016.

Data Collection

Data collection primarily involved face-to-face interviews with the respondents. Separate questionnaires were used for the quantitative and qualitative aspects. The quantitative questionnaire required a structured 30-minute to 40-minute session with the control and treatment households. For the qualitative assessment, the survey team undertook in-depth interviews and focus group discussions with the control and treatment households. Three focus group discussions were conducted in each location, involving eight or nine respondents. Of the three groups, one was exclusively composed of women.

Selection of Households for the Evaluation

A key challenge faced by the survey team during data collection was how to identify and contact the requisite number of treatment households. Since the treatment households were purchasing the solar lanterns on the market and not being given them, these households needed to be contacted on a real-time and ongoing basis. To capture the baseline data effectively, this exercise had to be performed within a relatively short time span.

The selection of treatment households, therefore, involved tracking a number of distribution channels, as described here:

Selection of the Treatment Households

Treatment households were selected for this study from among those that had purchased solar lanterns from the following sources.

- Microfinance Institutions (MFIs): Households were identified from databases of the provider MFIs.
- Sahaj Centres: Sahaj e-Village is an initiative introduced by SREI Infrastructure Finance Limited (SIFL), to provide information and communications technology (ICT) services in rural areas. Some Sahaj outlets in Uttar Pradesh and Bihar stocked and sold the solar lanterns.
- Suryoday Consumer Awareness Campaign: This campaign was launched by the IFC in 2014 to build the market for quality-assured solar lighting products. Some households that had purchased the product during the campaign were included in the survey.

For the baseline assessment, the treatment households were contacted within three or four weeks of their acquisition of a solar appliance, to document the prevailing lighting practices before the purchase. The assumption was made that household behavior did not change drastically within this period. In each household, one member with knowledge of the family income and expenditure, lighting device usage habits, and so on, was interviewed by the survey team.

Selection of the Control Households

Control households, those not in possession of any solar appliance, were identified and interviewed in the same villages as treatment households, or in adjoining villages. For the baseline evaluation, the survey team interviewed twice as many control households as treatment households. The greater sample size allowed the survey team to remove from consideration, at the midline or endline stage, any of the control households that had in the meantime acquired solar lanterns.

Sample Matching for Data Analysis

For the data analysis, the households were compared on the basis of sample equality and sample homogeneity. For sample equality, an equal number of control and treatment households were selected, to ensure balanced representation. For sample homogeneity, control and treatment households with similar socio-economic parameters and demographics were selected, to ensure that the comparative evaluation was meaningful. The number of households selected for the study is shown in Table 2.

Table 2. Number of Households Used in the Study, State-wise Division

Household category	All		Uttar Pradesh		Bihar	
	Baseline	Endline	Baseline	Endline	Baseline	Endline
Treatment	476	476	300	300	176	176
Control	476	476	300	300	176	176
TOTAL	**952**	**952**	**600**	**600**	**352**	**352**

Study Locations

The villages in which households were surveyed for this study are located in several districts across the states of Uttar Pradesh (Figure 1) and Bihar (Figure 2).

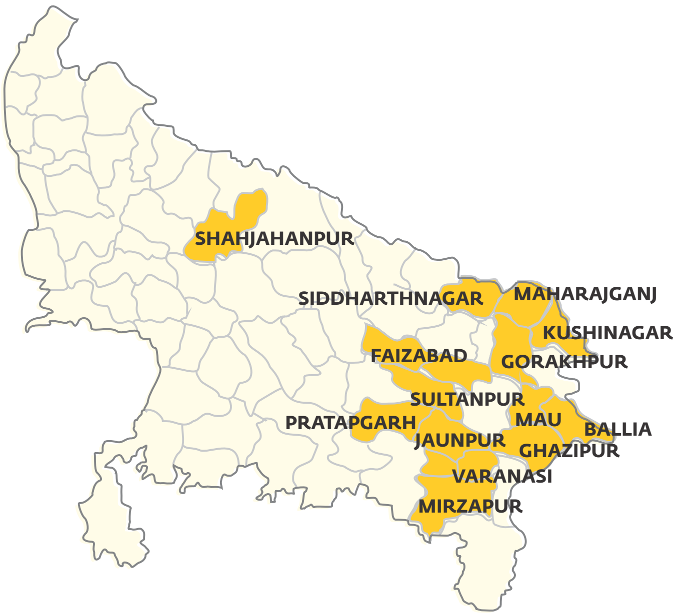


Figure 1. Survey locations (districts) in Uttar Pradesh

Figure 2. Survey locations (districts) in Bihar

Impact Parameters

To evaluate the impact of the solar lanterns, the study was designed to focus on the following parameters:

Fuel consumption and savings

The control and treatment households' relative consumption and savings or expenditure on kerosene, off-grid battery-based devices, and candles. The hypothesis was that treatment households would enjoy greater savings and reduced consumption of such products.

- **Kerosene consumption and savings:** Reduction in the regular duration of use of kerosene lamps in treatment households, corresponding to an increase in the duration of use of solar lanterns and a decrease in kerosene consumption.
- **Off-grid battery-based lighting devices consumption and savings:** The net savings, in treatment households, from a decrease in the usage and consumption of off-grid battery-based devices. This includes reduced expenditure on batteries for torches, and on charging rechargeable devices.
- **Candle usage:** Reduced candle usage in treatment households.

Education

Increase in children's study hours in treatment households, corresponding to reduced usage of other, cost-intensive lighting devices.

Behavioral changes

Evidence of a shift in the behavior and attitudes of treatment households toward solar-powered, non-traditional lighting devices, corresponding to a decrease in the use of traditional devices like kerosene lamps or cans with oil and wick. Evidence of positive change in these households' perception of the quality of domestic lighting.

Health

An expected decline in the incidence of respiratory ailments induced by kerosene lamp fumes.

Fire accidents and safety

A hypothesized decline in the number of fire accidents caused by traditional devices like kerosene lamps and candles, corresponding to their reduced usage.

Assessment Framework

In the study, two methods were used to measure impact: direct comparison and double difference. Direct comparison was done between the treatment and control households, at baseline and endline. Double difference was calculated as follows: [T(e) - T(b)] - [C(e) - C(b)], where:

- T(e) denotes the incidence of a parameter at endline among the treatment households.
- T(b) denotes the incidence of a parameter at baseline among the treatment households.
- C(e) denotes the incidence of a parameter at endline among the control households.
- C(b) denotes the incidence of a parameter at baseline among the control households.

Study Limitations

The study extended over two years. Its primary limitations reflect this duration, and include the difference in the assessment periods, and variations in the cost of kerosene over time.

Difference in period of assessment

The baseline data was gathered in the selected villages over six to eight months. As the sample required was large, it had to be drawn from multiple databases over this period, including the databases of the solar lantern retailers. Households were also enlisted directly by approaching customers at the solar lantern retail points. The baseline sample, therefore, was acquired over a period of time in different locations and from diverse sources. The endline assessments, however, were done simultaneously. Inevitably, the time between the baseline and endline assessments, while averaging seven months, was not uniform for all the surveyed villages.

Cost variations of kerosene

This study was performed over a period of two and a half years, during which the price of kerosene in India fluctuated in response to international crude prices. At the local level the purchase source, whether public distribution system or private trader, was another factor that acted on the price. The survey team approximated the kerosene prices reported by the households during the evaluation period at INR 20 per liter to INR 40 per liter. This range represents the average prevailing PDS or trader prices. It also covers the small number of survey respondents unable to recall the prices they had paid or reporting very low or very high prices.

Image: Philips Lighting India Limited

Results and Analysis

The results of the study are presented in the two following sub-sections. The first includes household data and insights. The second provides an impact analysis of the intervention.

Household Data and Insights

The household profiles, including affluence level, living conditions, and lighting practices are discussed in this section. These parameters remain broadly comparable for the control and treatment households.

Household Profile and Affluence Level

The household demographics were categorized as follows:

- **Family size and education:** Households had an average family size of five members, including at least one child. Households with at least one member educated up to the SSC/HSC level (10th grade in school) constituted 14 percent of the treatment group and 16 percent of the control group.
- **Occupation and income:** The average monthly household income ranged between INR 5,500 (USD 82) and INR 6,500 (USD 97) for control and treatment households respectively. Overall, there was a small difference in the pattern of monthly household savings. The survey respondents reported that the treatment households saved INR 1,536 (USD 23) per month; that is, INR 117 ($1.74) more than the controlled households at INR 1,419 (USD 21) - this is as per the figures quoted by the surveyed respondents. While agriculture appeared to be the primary employment for control as well as treatment households, treatment households were also seen to own small businesses like tailoring and grocery shops. A higher percentage of treatment households (28 percent) than control households (15 percent) had availed of loans. In most cases, the loans had been taken to meet household and business-related expenditures. (This difference in use of formal finance may be explained by the treatment households' slightly higher income and savings, which are likely to have made them more "bankable" than control households.)
- **Ownership of consumer durables:** Bicycles (79 percent in treatment and control households) and mobile phones (76 percent in treatment households, 79 percent in control) had maximum penetration. 30 percent to 45 percent of all the households owned grid-dependent appliances like fans and televisions.

Living Conditions

For treatment and control households, living conditions were assessed by the number of rooms in the dwelling, what fuel predominantly was used for cooking, and the nature of the household members' daily activities.

- **Quality of housing:** Most dwellings consisted of three water-proofed rooms. No major differences between the two groups were evident in terms of housing. 88 percent of treatment households had dwellings with brick walls, compared with 86 percent of control households.
- **Fuel usage pattern:** Wood was used as the sole fuel for cooking by 21 percent of treatment households and 25 percent of control households. LPG was used as a primary source of cooking fuel by 44 percent of treatment households and 41 percent of control households. Kerosene was used as a primary source for cooking by 23 percent of treatment households and 20 percent of control households.
- **Activities and routine:** In both control and treatment households, half the adults (48 percent) spent about nine hours a day on household chores, while 18 percent spent four hours a day on their work or business activity. The remaining time was spent on socializing, recreation, and shopping. Children spent two hours reading or studying during school hours and one hour during non-school hours. They spent about one hour playing and 20 minutes or 30 minutes completing household chores and engaging in other recreational activities.

Household Penetration of Lighting Devices

The presence of lighting devices such as kerosene lamps, off-grid battery devices, and candles was analyzed at baseline and endline in both treatment and control households. Table 3 shows the penetration levels of these lighting sources. The penetration of traditional devices, such as kerosene lamps, was 100 percent in treatment and control households. Kerosene lamps continued to be in use in the treatment households even after the intervention, because a single solar lantern did not satisfy the lighting requirements of an entire household.

Table 3. Levels of Penetration: Traditional Lighting Sources

S.No.	Lighting fuel/devices	Treatment HHs		Control HHs	
		Baseline	Endline	Baseline	Endline
1	Kerosene lamps	100%	100%	100%	100%
2	Off-grid, battery-based devices	4.60%	10.70%	7.10%	11.10%
3	Candles	17.00%	0.40%	4.40%	4.60%

The more expensive variety of kerosene lighting device — a kerosene lamp with a wick and glass shield — was more prevalent, at endline, in control households (43 percent) than treatment households (24 percent). Off-grid, battery-based devices like torches and emergency lamps were used by around 10 percent of all households at endline.

These results, revealing the persistence and even increase of off-grid battery based lighting, appear counterintuitive in the case of treatment households. This was, however, not a single-variable situation, and a number of factors were at play. Among these factors were market-related issues like the flooding of electronics markets with these low cost products and the continuing unreliability of grid electricity supply.

Grid Connectivity Profile

Table 4 covers grid penetration among the households. At endline, an overall 57 percent of both treatment and control households had access to the electricity grid[5].

Table 4. Levels of Penetration: Grid

Type of Energy Source	Treatment HHs		Control HHs	
	Baseline	Endline	Baseline	Endline
Grid	65%	57%	59%	57%

Among the households with access to the grid, all reported receiving electricity supply for about 11 hours per day. 98 percent of these households in the treatment group and 99 percent in the control group had only a single-phase connection. Continuous supply of electricity was elusive. 45 percent to 50 percent of the grid-connected households, whether in the control or the treatment group, described the quality of grid electricity as average. The key supply-quality issues they encountered were scheduled and unscheduled outages, voltage fluctuation, and low voltage.

[5] Some of the households were grid connected but had unmetered connections at the time of the baseline survey, and it is possible that these household grid connection status changed at the endline (i.e, they no longer had a grid connection at the time of the endline survey). Although the specific reason for this change was not collected from the survey.

Impact Assessment

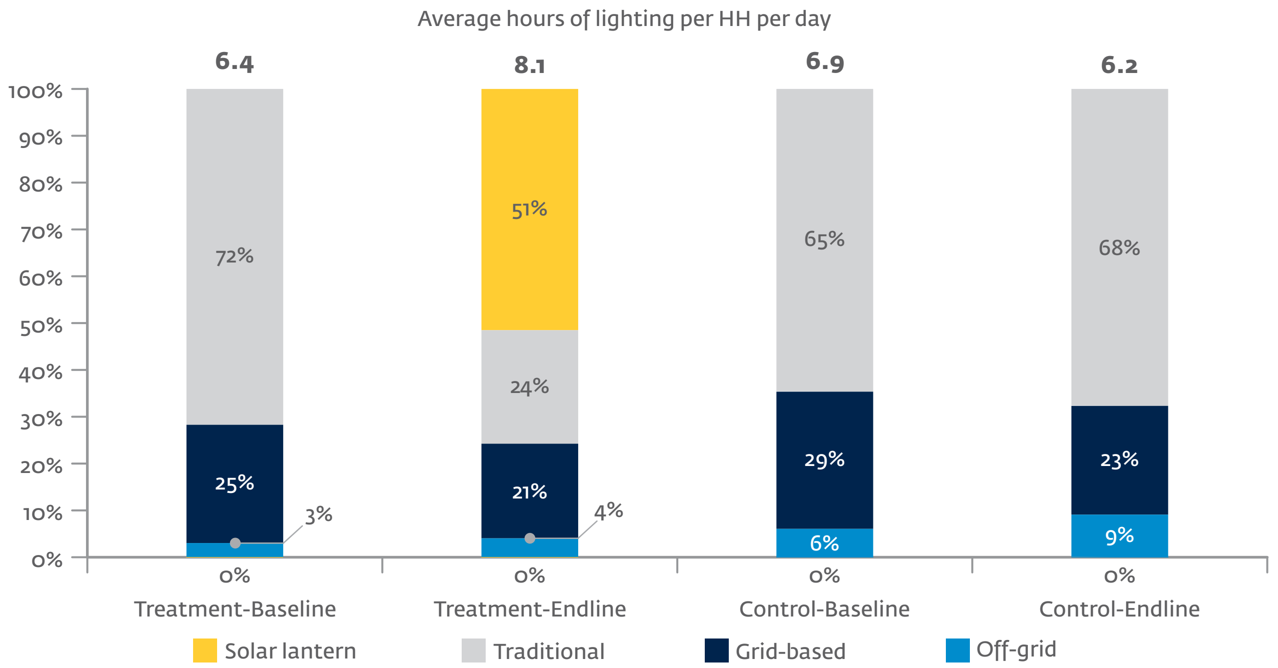
In the earlier section on methodology, this report lists the impact parameters chosen for assessing the intervention of solar lanterns. In the following section, this report will review the outcomes. It will begin with a measurement of total lighting hours. Next it will address fuel consumption and cost savings vis-à-vis kerosene devices, off-grid devices, and candles. Finally, it will examine the parameters of education, health, fire accidents and safety, and behavioral change.

Impact on Total Lighting Hours, Fuel Consumption, and Savings

As shown in Figure 3, the total lighting duration among treatment households was 6.4 hours per household per day at baseline, and 8.1 hours per household per day at endline. This represents an increase of 26 percent. The change is attributed to the solar lantern intervention and, to an extent, to the increased use of other off-grid battery-based devices.

Control households reported a decrease in total lighting duration from 6.9 hours per household per day at baseline to 6.2 hours at endline. This 11 percent decline is attributed to a reduced availability of grid electricity among control households connected to the grid, particularly during the early hours of the day. To offset this decline, these households had to step up their expenditure on traditional fuels and off-grid lighting devices.

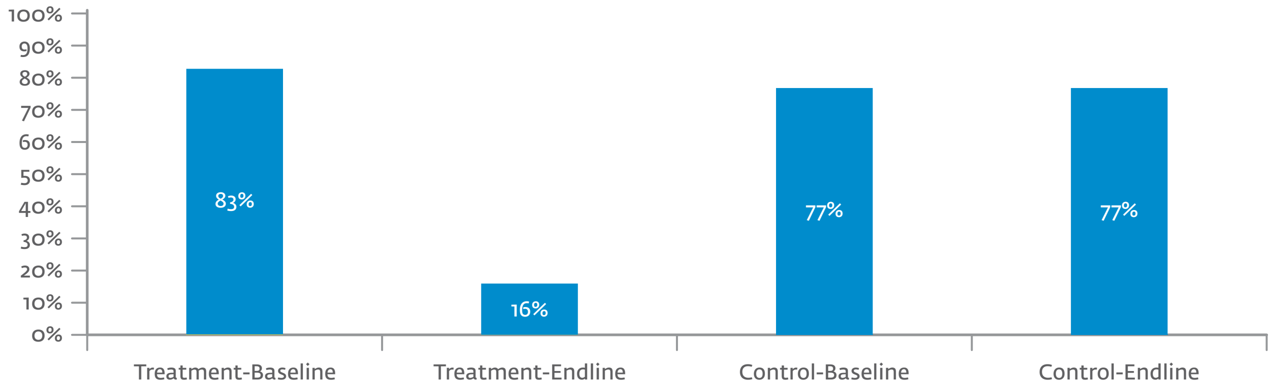
Figure 3. Usage of Lighting Devices at Baseline and Endline in All Households



Consumption and Savings on Kerosene

At baseline, approximately 83 percent of the treatment households used traditional devices such as kerosene lamps, candles, and oil lamps, as the main lighting source. After the intervention of solar lanterns, however, only 16 percent of these households reported a continued dependence on traditional lighting devices as the primary light source. Figure 4 captures this shift.

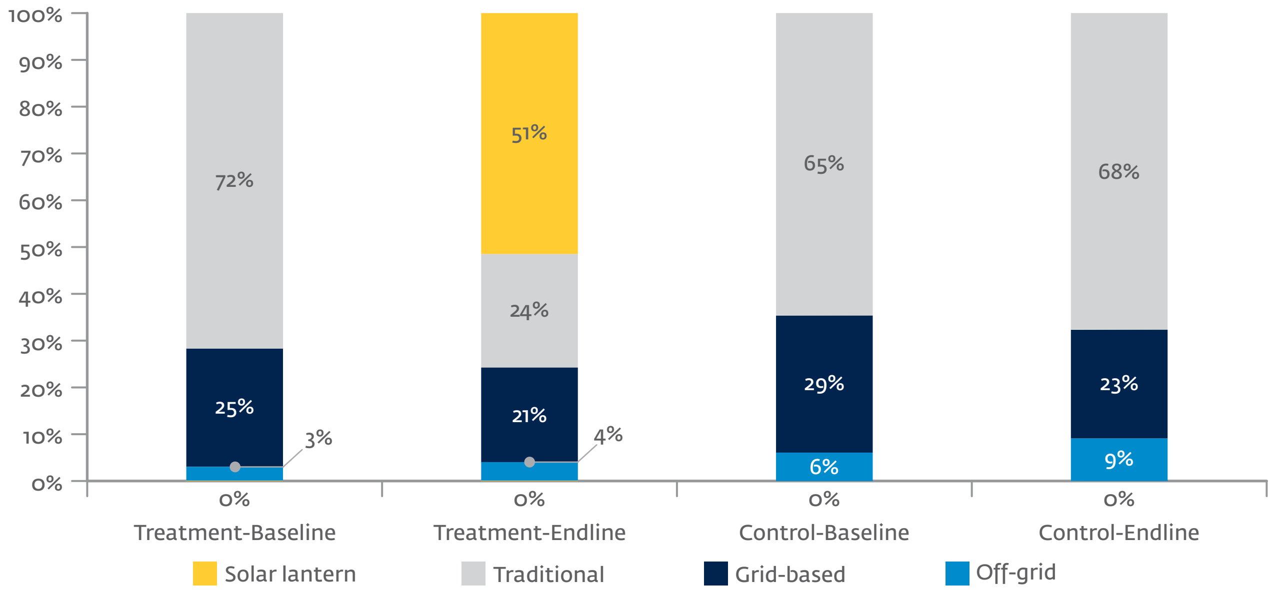
Figure 4. Usage of Traditional Lighting Devices at Baseline and Endline in All Households



The relative total usage hours per day for each category of lighting device are presented in Figure 5. Kerosene lamp usage declined significantly among treatment households between baseline and endline. Treatment households reduced their usage of traditional devices by nearly three hours per day, representing a 75 percent decrease from baseline (a statistically relevant drop). Control households also reduced their kerosene usage, by one hour per day, and this was attributed to their increased use of off-grid, battery-based devices.

The duration of use was further segregated by access to the electricity grid. Accordingly, while off-grid treatment households reduced their usage of kerosene lamps by three hours and nine minutes per day (a 74 percent decrease from baseline), those with grid connectivity reduced their usage by two hours and forty-six minutes per day (an 83 percent decrease from baseline).

Figure 5. Usage of All Lighting Sources at Baseline and Endline in All Households, in Hours per Day



A key positive impact of the solar lantern was the decreased quantity of kerosene consumed for lighting. There is a 41 percent decrease, among treatment households, from a baseline consumption of 3.12 liters of kerosene per household per month to an endline consumption of 1.84 liters per month (a statistically relevant drop of 1.28 liters per month). Among control households, a slight reduction was observed: consumption dropped from 2.82 liters per household per month to 2.38 liters per month (a difference of 0.44 liters). This could be attributed to the increased usage of off-grid, battery-based devices. A net reduction of 0.86 liters of kerosene per household per month was observed between the treatment and control households, by computing the double difference of kerosene.

As expected, the decrease in the duration of kerosene lamp usage, and therefore kerosene consumption, led to a reduction in expenditure on kerosene. Treatment households saved INR 23 (USD 0.34) per household per month, while control households experienced a statistically relevant saving of INR 6 (USD 0.09) per month.

By replacing fossil fuels solar lights reduce the amount of kerosene that is burnt in lamps, thereby reducing global warming. The environmental benefits of cutting the use of kerosene reduces greenhouse gas emissions. The Clean Development Mechanism (CDM) default value for this reduction is 0.092 tonnes/year CO_2e saved per solar light[6].

Consumption and Savings from Off-grid Devices

As for off-grid, battery-based devices, 11 percent of both control and treatment households used these at endline. Treatment households continued to spend on such lighting devices despite the intervention of solar lanterns. Control as well as treatment households spent marginally more on off-grid battery-based devices than at baseline. These results could reflect two external factors. First, the winter season, during which the solar appliance cannot be charged to its optimum capacity. Second, the incidence of households without access to reliable electricity supply. Accordingly, households in both groups continued to use the off-grid lighting devices; households at the higher end of the sample's income range were overwhelmingly likely to own these devices.

At endline, the treatment households' expenditure on candles had decreased by INR 6 (USD 0.09) per household per month. Among control households, expenditure on candles remained constant.

> **Battery-based devices over traditional devices:** "If kerosene is not available, how will people use it? Even 5 liters of kerosene if used for lighting will not be enough for a month, but if you buy this 100-Rupee emergency lamp, it will work for months."

Overall Impact on Savings and Expenditure

A significant measure of the overall impact of the intervention, as captured by the study, was the households' expenditure on lighting devices. At baseline, kerosene purchases represented the bulk of this expenditure. The study assumed that, in the treatment households, kerosene purchases would decrease after the introduction of solar lanterns.

The savings were computed by making a direct comparison between treatment and control households, at baseline and then at endline, of the amount spent on kerosene, candles, off-grid devices, and mobile charging. Table 5 presents these details. On kerosene alone, the data show that treatment households saved significantly more than control households. Treatment households saved an average of INR 300 (USD 4.47) per year, overall, of which INR 265 (USD 3.95) was saved on lighting devices. In other words, the solar lantern intervention saved these households INR 265 per year.

One item of expenditure did increase among treatment households: off-grid, battery-based devices. This, the study indicates, may be because the treatment households had a slightly higher average income, making them more willing to buy rechargeable lamps and batteries for torches.

On mobile charging, control households managed to save INR 42 (USD 0.62) per household per year, while treatment households saved INR 35 (USD 0.52). This occurred because, between baseline and endline, control households turned to charging their mobile phones at the homes and shops of neighbors or friends, at no cost to themselves.

Table 5. Overall Savings and Expenditure in All Households

S. No.	Savings/Expenditure Status	Treatment	Control
		Amount per HH	Amount per HH
1	Savings from kerosene	(-) INR 276 (USD 4.12)	(-) INR 72 (USD 1.07)
2	Savings from candles	(-) INR 72 (USD 1.07)	INR 0
3	Expenditure on off-grid, battery-based devices	INR 83 (USD 1.24)	INR 25 (USD 0.38)
Savings from lighting fuel/devices		**(-) INR 265 (USD 3.95)**	**(-) INR 47 (USD 0.70)**
4	Savings from mobile charging	(-) INR 35 (USD 0.52)	(-) INR 42(USD 0.62)
Aggregate savings per year (lighting + mobile charging)		**(-) INR 300 (USD 4.47)**	**(-) INR 89 (USD 1.32)**

[6]Small-scale Methodology, Substituting fossil fuel-based lighting with LED/CFL lighting systems, Version 06.0, Sectoral scope(s): 01. https://cdm.unfccc.int/filestorage/O/2/H/O2HGLE9V8CFPA07I6YT3XZNSUK1BDM/EB100_repan13_AMS-III.AR.pdf?t=TGp8cGxldmdpfDAYQEvwimjaL2WXhmPsMCDV

Savings and Expenditure in Households with Grid Connectivity

Among households with grid connectivity, treatment households saved INR 276 per year on kerosene while control households saved INR 72. Both groups of households incurred expenses on off-grid, battery-based devices, probably due to inconsistent grid connectivity. The fact that treatment households spent a little more on these devices was attributed to their marginally higher income. The minimal mobile charging expense among treatment households indicates savings owed to the solar device.

Savings and Expenditure in Households without Grid Connectivity

Treatment households without access to grid electricity saved INR 240 (USD 3.58) per household per year by reducing their usage of kerosene. Control households, too, saved on kerosene, but less than half as much, or INR 108 per year. It is likely that some control households were able to save on kerosene by renting electricity connections from other nearby, grid-connected households, or by obtaining illegal electricity connections.

Table 6. Savings and Expenditure in Households with Grid Connectivity

S. No.	Savings/Expenditure Status	Treatment	Control
		Amount per HH	Amount per HH
1	Savings from kerosene	(-) INR 300 (USD 4.48)	(-) INR 24 (USD 0.36)
2	Savings from candles	(-) INR 56 (USD 0.83)	(-) INR 1 (USD 0.02)
3	Expenditure on off-grid, battery-based devices	INR 100 (USD 1.50)	INR 68 (USD 1.01)
Savings in treatment HHs and expenditure in control HHs from lighting fuel/devices		**(-) INR 256 (USD 3.82)**	**INR 43 (USD 0.64)**
4	Expenditure on mobile charging	INR 1 (USD 0.01)	INR 48 (USD 0.72)
Aggregate savings / expenditure per year (lighting + mobile charging)		**(-) INR 255 (USD 3.81)**	**INR 91 (USD 1.36)**

The survey results indicated that control households saved marginally more on mobile charging than treatment households. Off-grid control households, like grid-connected households, appeared to have switched to mobile charging through means that incurred no expense.

Overall, treatment households experienced higher savings on lighting fuel and devices. This was interpreted as a positive impact of the intervention. Table 7 presents these details.

Table 7. Savings and Expenditure in Households without Grid Connectivity

S. No.	Savings/Expenditure Status	Treatment	Control
		Amount per HH	Amount per HH
1	Savings from kerosene	(-) INR 240 (USD 3.58)	(-) INRs 108 (USD 1.61)
2	Savings from candles	(-) INR 86 (USD 1.28)	(-) INR 1 (USD 0.01)
3	Expenditure on off-grid, battery-based devices	INR 57 (USD 0.85)	INR 58 (USD 0.87)
Savings from lighting fuel and devices		**(-) INR 269 (USD 4.01)**	**(-) INR 51 (USD 0.76)**
4	Savings from mobile charging	(-) INR 103 (USD 1.53)	(-) INR 168 (USD 2.51)
Aggregate savings / expenditure per year (lighting + mobile charging)		**(-) INR 372 (USD 5.55)**	**(-) INR 219 (USD 3.27)**

Impact on Education

Children studied longer hours as a result of the intervention. Study time increased by 52 minutes per treatment household per day. Control households, too, reported an increase in children's study duration, but it was smaller at 34 minutes per day.

Study hours were also recorded for grid-connected and off-grid households. Children in off-grid treatment households were found to be studying 1 hour and 19 minutes longer per household per day. Children in off-grid control households maintained the same duration of study from baseline to endline. Children in grid-connected treatment households studied an extra 44 minutes per household per day. Finally, children in grid-connected control households studied an additional 30 minutes per day from baseline to endline - an improvement that was attributed to a small increase in the use of off-grid, battery-based devices for lighting.

> "Earlier, they used to study under the kerosene lamp, but they did not feel like studying under that. The children started studying after we got this [solar lantern]" – Respondent, Bihar

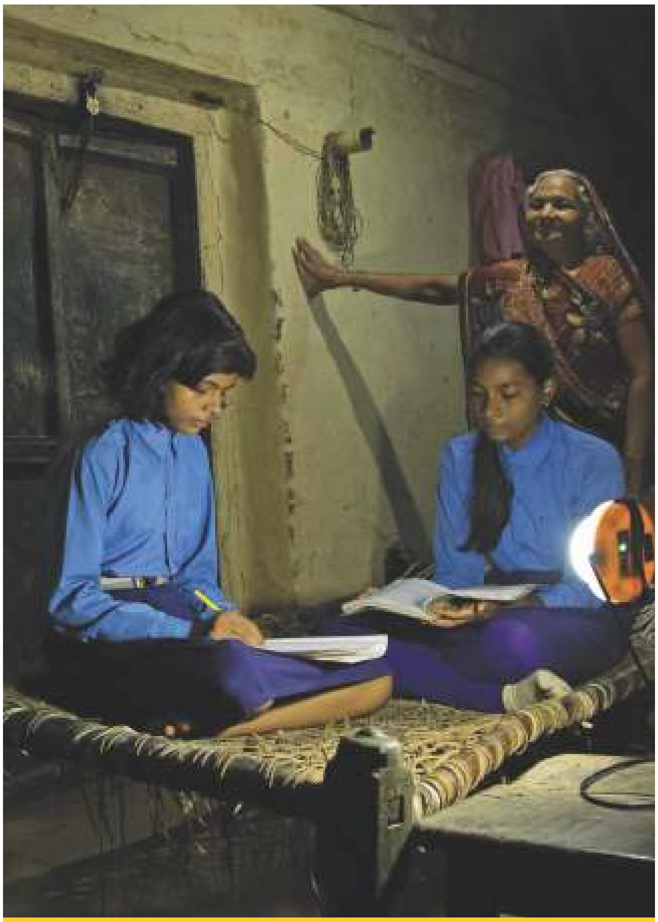


Image: greenlight planet

Figure 6. Distribution of All Lighting Sources for Studying, in Hours per Day

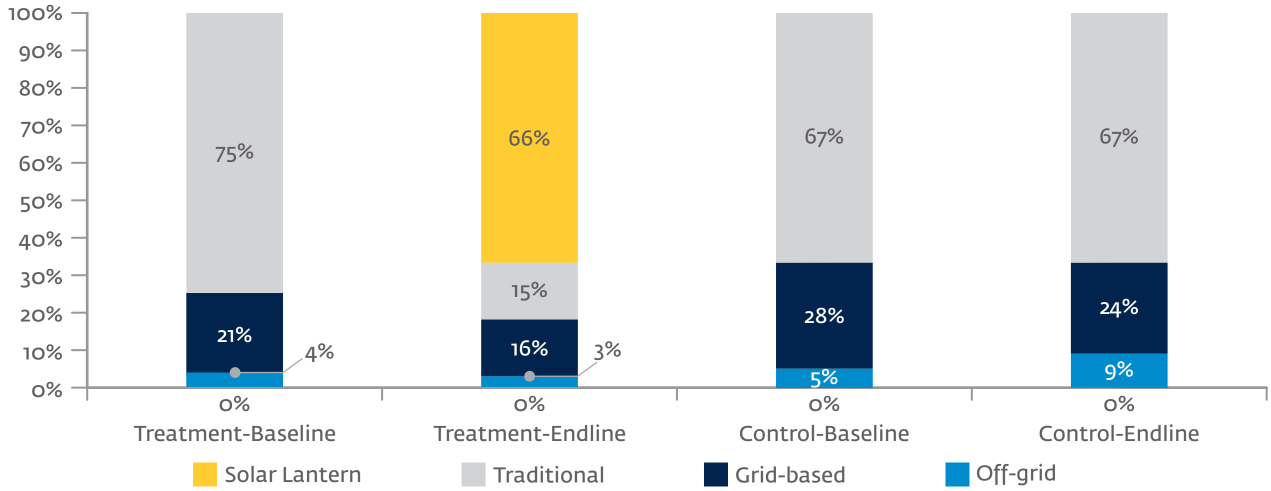


Figure 6 displays how much each light source was used, relative to all others, for studying. In treatment households, children used the solar appliance for more hours than they used the kerosene lamp. Children in control households studied using primarily the traditional and off-grid devices.

Behavioral Changes

This section details the shift in behavior and attitude of the households towards the solar appliances as well as towards traditional lighting devices.

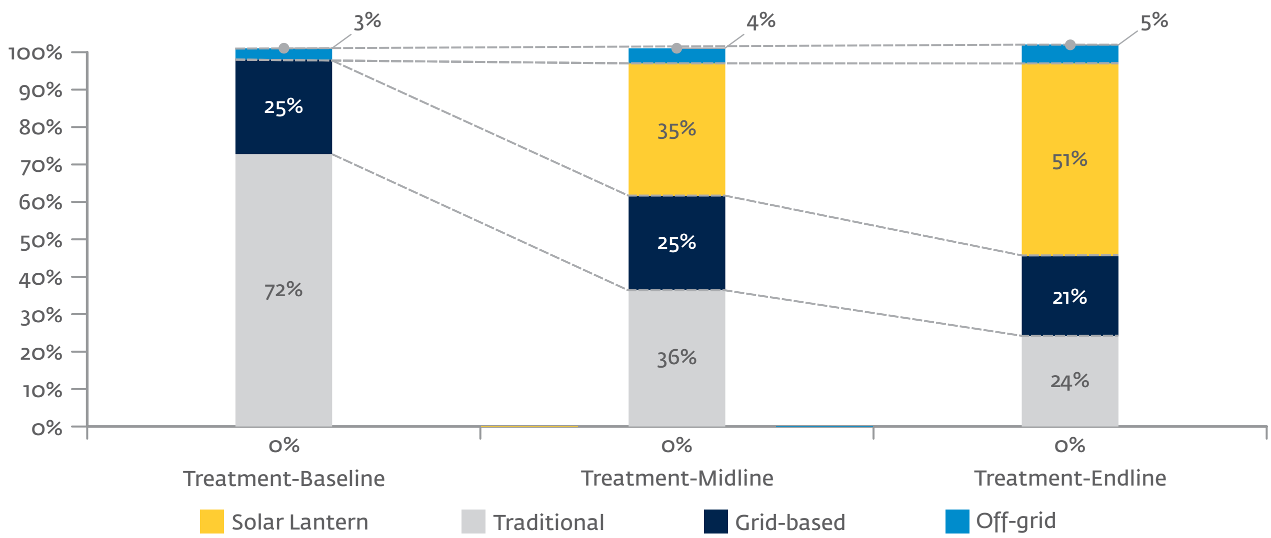
Changes in Solar Lantern Use

The study drew the following insights about solar lantern usage from the survey and from focus-group discussions involving the treatment households.

- **Reasons for purchase:** Treatment households said that they purchased the solar lanterns as a brighter lighting option for the house. They wanted to avoid the recurring fuel cost of kerosene, and the negative health impact of traditional lamps.
- **Place of use:** Most treatment households said they used the solar lighting devices predominantly in the kitchen and bedroom, followed by the hall and other areas of the house.
- **Productive applications:** Although the study focused on household activities, the survey team received anecdotal evidence that the solar lanterns had a positive impact on occupations, such as tailoring, that involved piecework done at home.
- **Usage trends:** Figure 7 represents the relative share of usage hours of various lighting devices in the treatment households. It reveals an intensification in the use of solar lanterns from midline to endline. It shows a progressive shift towards the use of the solar lantern and a commensurate reduction in the use of traditional kerosene-based lamps for domestic lighting.


Image: d.light

Figure 7. Distribution of All Lighting Sources Used per Day for Household Activities

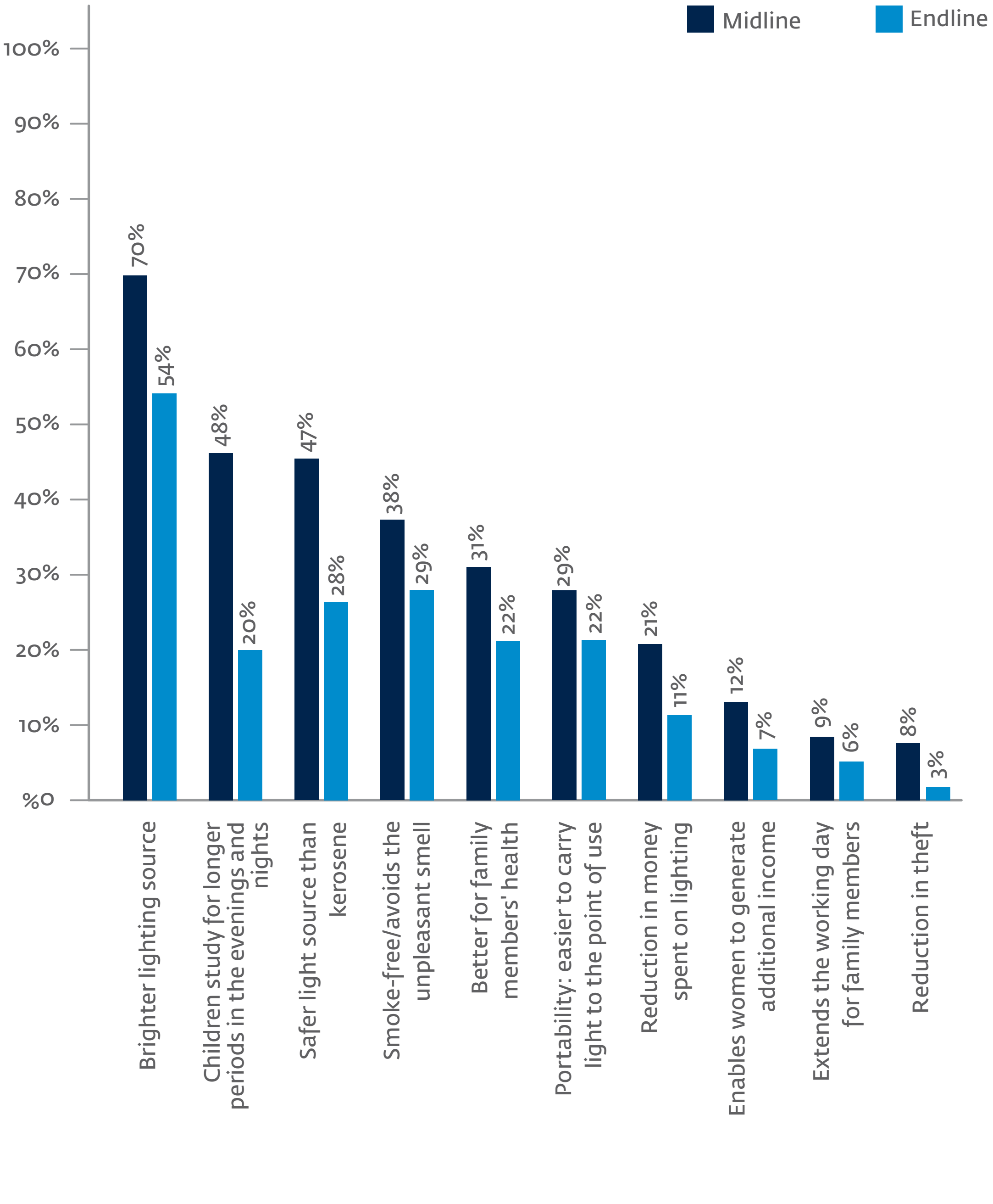


The marginal increase in the use of off-grid, battery-based devices (from 3 percent at baseline to 5 percent at endline) was attributed to a decline in the availability of grid electricity over the period of the survey.

Perceived Benefits of the Solar Devices

The main benefits, according to the treatment households, included a brighter domestic light source, longer hours of study for children, and increased health and safety for the family members. A significant number of households mentioned the portability of the lighting unit and the reduced household expenditure as key benefits of the solar light. These perceived benefits were given more importance at midline than endline (see Figure 8), possibly because the novelty factor of the solar appliance had worn off by endline.

Figure 8. Comparison of Perceived Benefits at Midline and Endline



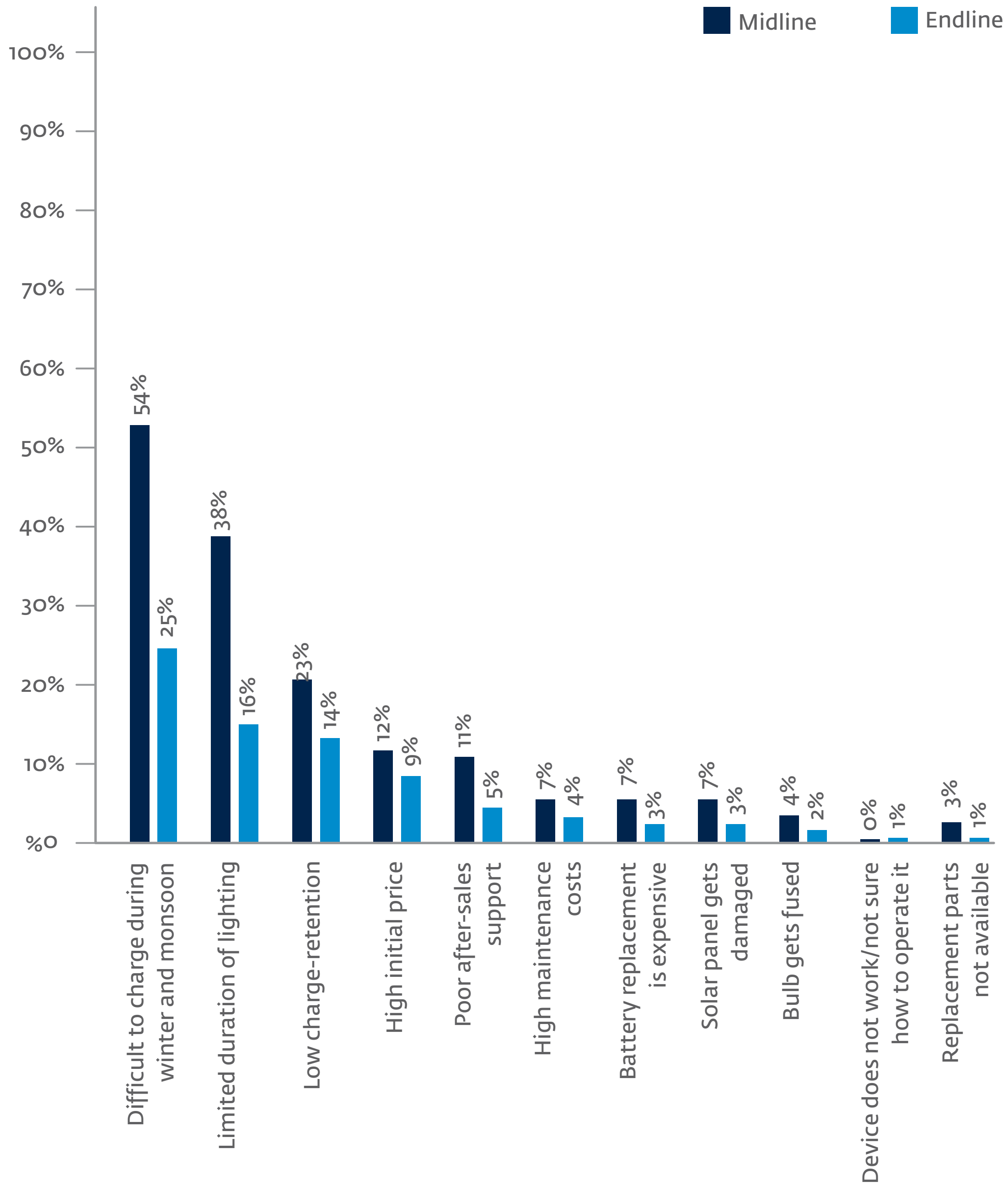
Difficulties / Problems Faced in the Use of the Solar Devices

The treatment households reported a number of challenges they faced in using the solar lanterns, at midline and endline. Figure 9 presents the most common such instances.

Among them was cost: the initial purchase price was considered high. Other challenges included difficulties of use, such as poor solar charging during the winter and rainy seasons, insufficient charge to last late into the night, and overall low charge-retention by the battery.

The considerable reduction in the reporting of such problems at endline, the study explained, could be because of the treatment households' greater familiarity with the appliance, and therefore their more realistic expectations of its functioning.

Figure 9. Difficulties and Problems faced with the Solar Appliances



Health

One of the anticipated outcomes of the intervention was a reduction in respiratory and related ailments induced by fumes from the kerosene lamps. The findings, however, revealed a marginal increase in the incidence of such ailments among treatment households, from 15 percent at baseline to 19 percent at endline. A marginal increase in these ailments was likewise noted among control households, from 13 percent at baseline to 16 percent at endline.

Computing the double difference at endline and baseline among treatment and control households, however, the study calculated a net increase of 1 percent in the incidence of ailments. Thus, no substantive impact on this parameter was evident by the end of the intervention period.

Fire accidents and safety

Neither treatment nor control households experienced any change in the incidence of fire accidents. The double difference computation showed a zero percent effect on fire accidents from baseline to endline. The intervention, therefore, had a very minimal or zero impact on the incidence of fire accidents.

Conclusion

This study examined the impact of the intervention of solar-powered lanterns on households in rural north India, over a period of 2.5 years. Over this period, the study obtained clear and relevant results in a number of parameters. The most dramatic indicator of impact was the divergence in the consumption of and savings on kerosene between the treatment and control households. Other notable positive effects included an increase in the number of hours of light available for children to study and for adults to pursue other household and income-generating activities.

Many Indian villages that are officially electrified contain a mix of households with and without access to grid electricity. The study confirmed that the intervention of solar lanterns holds out benefits to all such households. Given that even grid-connected households in rural India face 11 hours to 15 hours of power cuts every day, including during the evening and night, solar lanterns are an effective way of supporting their lighting needs. Non-electrified villages tend to receive the bulk of such interventions, but the findings of this study highlight the need in electrified villages as well. Rural electrification is spreading at a rapid pace in India, but solar appliances remain a meaningful way to bridge some of the obvious and persistent supply-side gaps.

Image: ovSolar

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About Lighting Asia/India

Lighting Asia/India is an IFC program that aims to increase access to clean, affordable energy in rural India by promoting modern off-grid lighting products and systems, and efficient DC appliances. The program works with the private sector to remove market entry barriers, provide market intelligence, foster B2B linkages and raise consumer awareness on modern lighting options. Over the next 3 years, the program will focus its efforts in the states of Bihar, Uttar Pradesh, Rajasthan, Odisha and Assam.

Lighting Asia/India Program is implemented in partnership with Australia, Austria, Canada, Hungary, Iceland, Italy, Luxemburg, Netherlands and Norway.

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About Lighting Global

Lighting Global is the World Bank Group's platform to support sustainable growth of the international off-grid solar market as a means of rapidly increasing energy access to the 1.2 billion people without grid electricity. Through Lighting Global, the International Finance Corporation (IFC) and the World Bank work with the Global Off-Grid Lighting Association (GOGLA), manufacturers, distributors, and other development partners to develop the modern off-grid energy market. The Lighting Global program supports market development by working with private companies to lower first-mover risk and mobilize private sector investment through market intelligence, quality assurance, business support services and consumer education.

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