d.light Solar Home System Impact Evaluation

D.LIGHT SOLAR HOME SYSTEM IMPACT EVALUATION

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ABOUT THIS REPORT

d.light is a global social enterprise delivering affordable solar-powered solutions designed for the one billion people in the developing world without access to electricity and many more without reliable access. d.light provides distributed solar energy solutions for households and small businesses that are transforming the way people all over the world use and pay for energy. d.light is committed to tracking and validating the social impact. As such, d.light commissioned IDinsight to conduct a rigorous impact evaluation on the effects of a solar home system on consumer households. This research was also generously supported by USAID from the American People; the Shell Foundation, an independent charity; and by UK aid from the UK's Department for International Development (DFID). The views expressed are those of the authors and do not reflect the opinions of the funders.

I. Executive Summary

Background

This report summarizes the findings from the impact evaluation of d.light's D20g solar home system go-to-market pilot in southeastern Uganda, conducted by IDinsight and funded by USAID from the American People; the Shell Foundation, an independent charity; and UK Aid from the UK's Department for International Development (DFID).

The primary objective of the impact evaluation was to quantify social benefits obtained from owning the D20g system for the average customer in southeastern Uganda. The evaluation also examined consumer satisfaction, preferences, and habits.

Methodology

The evaluation employs a matching design[i] with difference-in-differences analysis.[ii] For the baseline survey, 500 households that had recently purchased d.light D20g solar home systems ("d.light households," which constitute the treatment group in the evaluation) and 1,500 comparison households were interviewed between mid-January and early May 2014. From the pool of 1,500 comparison households, the 500 households that were most similar to the d.light households on a number of observable characteristics were selected, using a statistical matching technique. These 1,000 households were interviewed again between late August and October 2014, in order to measure the changes that occurred over that period for both groups and to calculate the differences between the two groups. Since the two groups were nearly identical at baseline, any differences at endline can be attributed to ownership and usage of the d.light D20g solar home system.[iii]

Findings[iv]

All impact estimates reported below are statistically significant at the 5% level, unless otherwise noted. Each impact estimate also notes in parentheses the corresponding percentage change of the impact relative to what we would expect had the d.light households not purchased the D20g system. Note that these findings apply specifically to the context of this study; as with any study, caution should be taken not to overgeneralize outside the scope of the study's demographic, geography, and solar product.

Profile of respondent households

- The majority (85%) of households live in a rural area.
- Just over half of these households (52%) are likely to live under a base-of-the-pyramid poverty line ($2.50/day per capita, 2005 PPP).
- Daily household budget is estimated at $2.12, for an annual total of $773.80 (2014 USD).
- Small kerosene candle "tadooba" were the most common primary baseline lighting source across all income levels except for the top third, in which the prevalence of flash-

lights[v] is slightly higher. Households generally use 2-3 different low-quality lighting products to meet daily lighting needs.

Lighting usage

For the purposes of this report, "low-quality" lighting sources include tadooba (kerosene candles), kerosene lanterns, flashlights and other battery-driven lights, and wax candles. "High-quality" lighting sources include electric light from a solar system or lantern or a fixed electric light source powered by electricity or a generator. These are sources that give off electric light, rather than a flame which is less bright and produces fumes, and typically in a greater quantity than a flashlight.

- d.light households consumed 4.3 fewer hours of low quality light (a *63% decrease*) and 6.2 more hours of high quality light than comparison households (a *157% increase)*, for a net result of 2.9 additional hours of lighting per day, an increase of 29%—representing meaningful gains in the quality and quantity of household lighting.

Productive time

This study found that there is no statistically significant increase or decrease on the amount of time that d.light households spend on productive activities (income generating activities, chores, and study) as compared to the control households. It is possible that the increase in lighting hours observed could be largely spent on overnight security lighting.

Energy expenditure

A financed D20g costs approximately $230 in Uganda: households make a deposit of approximately $30, and pay approximately $0.60 per day over the course of a year. As such, while d.light customers may spend less on other energy costs, they do not experience immediate savings due to the cost of purchasing the D20g.

- As d.light customers started using the D20g system, they spent considerably less on non-D20g lighting sources (*-51%*), phone charging (*-84%*), and transportation to purchase fuel/batteries (*-93%*).
- However, since d.light customers have been making incremental payments during the first year of ownership, their overall energy costs are higher until the system is fully paid off.
- After paying off the D20g system, d.light households are expected to spend *$1.41* less per week on average than the comparison group on these same overall energy-related expenditures (*-73%*).
- It would take d.light households an estimated 3.1 years on average to recover the cost of the D20g system. Over d.light's expected minimum unit lifetime of 5-years,[vi] households would save *$138* in total energy and phone charging expenditures relative to what their expenditures would have been without the D20g system, while using more hours of lighting than they did previously.

- The percentage of overall household expenditure d.light households spend on energy therefore evolves from 13% monthly before buying a D20g, to 40% in Year 1 while paying for the D20g, and would drop to 3% in subsequent years (assuming constant consumption over time). This means households would free up 10% of their monthly expenditure for the lifetime of their product once it is paid off.

Socioeconomic status

- d.light households did not experience statistically significant changes in self-reported socioeconomic measures relative to the comparison group, nor in ownership of liquid household assets (as a proxy for savings).

Health & personal safety

d.light households reported health and safety improvements as a result of owning the system. Specifically:

- As compared to the control group, d.light households reported experiencing an 88% reduction in the reported incidence of burns (*-6.4 percentage points*) and a *93%* decrease in reported incidence of fires (*-6.0 percentage points*).
- The reported incidence of coughing also reduced among d.light households by 12% (*8.5 percentage points)*, though this finding was not statistically significant at the 5% level.
- There was no statistically significant impact on self-reported health levels.

Additional analysis on consumer insights

- On average, d.light households reported being satisfied with the D20g solar home system (7.0 on a scale from 1 to 10, 10 being the most satisfied).
- 95% reported increased happiness and satisfaction with their home as a result of having purchased the system.
- 97% of customers reported they have told friends and family to buy the D20g.

In summary, this evaluation shows that, over a period of 6 months, households that owned the D20g system experienced the following differences compared to what they would have experienced had they not owned the system:

- Increases in total light usage (increasing high-quality light usage while decreasing low-quality light usage);
- Projected decreases in lighting and phone charging costs over a 5 year period (with increased lighting costs in the short term);
- No increase in productive hours spent on chores, income-generating activities, or studying;
- No impact on reported socioeconomic status or asset accumulation; and
- Practically significant decreases in reported incidence of fires, burns, and coughs,[vii] but no impact on self-reported health status.

Limitations of this study

This study rigorously examined the impact of owning a d.light system on the outcomes of interest described above and is able to adequately offer a causal interpretation of owning a d.light system in the study's particular context. However, while interpreting the results it is worth keeping in mind the study's limitations.

External Validity

As with any study, it is important to not overgeneralize findings beyond the context of this study in terms of the type of product (D20g solar home system), the population sampled (d.light customers and matched households), geographic scope (southeastern Uganda), time range of the study (6-7 months), and the methods and metrics used (details in full report). As such, we urge caution when trying to generalize from any findings.

Internal validity: Evaluation method

While the most rigorous method for this study would have been a randomized controlled trial, which would have randomly assigned households to receive the D20g home system or not, this method would have radically altered the marketing, sales and distribution model, limiting the ability to draw lessons for scale up in Uganda. Instead, the study used a method of matching on observable characteristics, as it minimized operational disruption, providing a more accurate estimate of the impact of the entire model at scale. However, this method is limited by not being able to control for unobservable characteristics that might have been different between d.light and comparison households.

Internal validity: Metric Measurement

This evaluation relied on self-reported measures for lighting usage, time spent on productive activities, and health. Direct observation would have been preferred, but was not feasible due to time and budget constraints, as well as questions of the feasibility of spending many nights with rural households.

II. Introduction

Over one billion people lack access to electricity, 97% of whom live in sub-Saharan Africa and Asia.[viii] When considering a range of solutions to address this lack of energy access, it is important to note that while grid extension may make sense for densely populated urban areas, 85 percent of the world's un-electrified are in rural locations where transmission losses and capital costs can outweigh the benefits of electrical grid extension.[ix]

This need for energy has led to the development of a fast-growing, distributed, renewable energy market seeking to address an underserved, impoverished market. d.light's D20g solar home system is one such product designed for this market. The D20g system consists of a small solar panel which powers up to four LED light bulbs, one portable lantern, a cell phone charger, and a radio. Customers pay for the D20g in installments through a pay-as-you-go mobile money enabled system.

Implementers and supporters alike aim to create a wide range of social impacts with solar light and power products designed for homes and businesses in the developing world. Yet to date, there has been little research to actually test whether such solar light and power products actually improve incomes, health, or other socioeconomic conditions.[x]

This summary report is a synthesis of a rigorous impact evaluation of 483 households (85% rural) in southeastern Uganda using the d.light D20g solar home system as compared to 488 control households. This study, conducted by IDinsight, investigates the social impact of one of d.light's products, the D20g solar home system, for the average customer in the region over a six to seven month period. We believe that this is a contribution to the body of research of the industry, and the findings point to the need for further research to investigate a broader range of solar applications in a wider geographic scope.

Key outcomes of interest identified a priori can be broadly organized into the following categories:

- Changes in socio-economic situation through reduced energy expenditures and increased productive time in the evening, including potential educational benefits in the form of additional time available for studying;

- Reduction in adverse health and safety outcomes from being near flames and breathing fumes caused by fossil fuel-based lighting sources; and
- Overall satisfaction and quality of life improvements.

Information on household demographics and consumer satisfaction, preference, and habits was also captured in order to build additional learning to inform future iterations of the product, service, and business model.

Literature review

Results of the D20g study should be viewed in the context of similar studies, many of which helped inform our research design, in order to understand implications of owning solar products more broadly.

Previous studies find mixed results on the impact of solar lighting products on time spent on productive activities. Grimm et al. (2014),[xi] in a randomized controlled trial in Rwanda of a smaller solar system, find that households use 15% more hours of light, but observe no significant change in the hours spent on chores (by adults) or studying. They do note that household members often used solar lighting for these activities when they either didn't use a lighting product or used a non-solar light source before, with children shifting studying time from the afternoon to the evening. Furukawa (2013),[xii] in a randomized controlled trial in rural Uganda of solar lamps, finds an increase in self-reported hours spent studying but, curiously, a slight (statistically insignificant) decrease in test scores. Samad et al. (2013),[xiii] using household survey data to examine usage of a high-capacity solar home system in Bangladesh, find increased evening studying hours.

Several studies have found modest positive impact on respiratory health, due to reduced indoor air pollution from fossil fuel emissions and fire safety, though long-term health impacts of solar lighting products have not been studied and remain unclear. Grimm et al. (2014) find improved self-reported air quality, but no impact on respiratory disease symptoms and eye problems. Furukawa (2012),[xiv] in another randomized experimental study of solar lamps given to children in Uganda, finds modest improvements in air quality-related health and decreased probability of fires and burns. Hanna et al. (2012),[xv] in a longer-term study of clean cook stoves, find that while inhaled smoke decreased during the first year, there was no long-term impact on inhaled smoke and no ultimate health benefits.

III. METHODOLOGY

This study uses the quasi-experimental methodology of matching with difference-in-differences analysis in order to estimate the causal impact of the d.light D20g system on household outcomes of interest.[xvi]

For the baseline survey (January-May 2014), IDinsight interviewed 494 households in which someone purchased a d.light solar system ("d.light households," which constitute the treatment group under evaluation), sampled to be representative of the overall customer base in the region. At the time of the survey, in Uganda, the D20g system had only been marketed in districts in the southeastern part of the country, from which customers were sampled.[xvii] A random[xviii] sample of 1,483 households in neighboring villages that did not purchase the d.light D20g system was also interviewed to establish a comparison group. Subsequently, IDinsight employed a matching technique to select 488 households from the comparison group that are as similar as possible to the d.light households, except that the comparison group has not purchased the d.light solar home system.[xix]

d.light households and this sub-selection of comparison households were surveyed a second time between late August and October of 2014, an average of 6-7 months after the initial interview, in order to measure the changes that occurred over that period for both groups. The change between baseline and endline in the treatment group was compared with the change between baseline and endline in the comparison group, in order to determine how much the D20g impacted owners' lives compared to the comparison group.[xx] This "difference-in-differences" estimates the impact that can be attributed to ownership of the d.light solar system on the households that purchased the system.

The analysis in this report is based on survey[xxi] data from 971 households (483 d.light; 488 comparison).[xxii]

Limitations of this study

This study rigorously examined the impact of owning a d.light system on the outcomes of interest described above and is able to adequately offer a causal interpretation of owning a d.light system in the study's particular context. However, while interpreting the results it is worth keeping in mind the study's limitations.

External validity

This evaluation was designed to inform USAID's Development Innovation Ventures team on the impact of this product on the lives of those who purchased the D20g solar home system. As with all impact evaluations, it is important to not overgeneralize findings. These are the results of one evaluation, of one solar home system, in one part of one country, using a particular evaluation design and specific metrics, at one point in time. By itself, it gives limited information of the potential of other solar products, or even of the same solar product in very different locations. Additionally, due to differences between d.light customers and the overall population of eastern Uganda, results of this evaluation should not be extrapolated to the population at large and are instead restricted to households similar to these d.light households. Extrapolating beyond the evaluation context requires a detailed understanding of the product, the populations, and how people might use the product to their benefit. We urge caution when trying to generalize from any positive or negative findings.

Evaluation method and internal validity

The most rigorous evaluation design would have been a randomized controlled trial, which would have randomly given D20g home systems to some households and not to others. Households with and those without d.light systems would be nearly identical at baseline in all ways. This would allow unambiguous attribution of any differences at endline to ownership of the d.light home system.

This method was not feasible or desirable for several reasons, including that randomization would have radically altered the marketing, sales and distribution model, which would have limited the ability to draw lessons for scale up in Uganda. Instead the study identified a sample of individuals who chose to purchase the d.light home system and matched that sample to comparison households (i.e. without the home system) based on observable characteristics. This allowed d.light and their partner organization to proceed without any operational disruption, allowing their entire model to be evaluated and providing a more accurate estimate of their impact at scale.

The limitation of this method is that it cannot control for unobserved characteristics that may differ between d.light and comparison households. In other words, even though comparison households surveyed looked similar to d.light households, it is possible that d.light and comparison households may still differ in an unobserved way that could account for differences in outcomes: for example, households that purchase D20g home systems *might* be more interested in adopting novel technology, more willing to take bigger risks, more motivated to improve their wellbeing, and so on. To minimize the risk that unobserved characteristics might drive any impacts, IDinsight selected our comparison households among villages that were less likely to have come into contact with d.light systems.

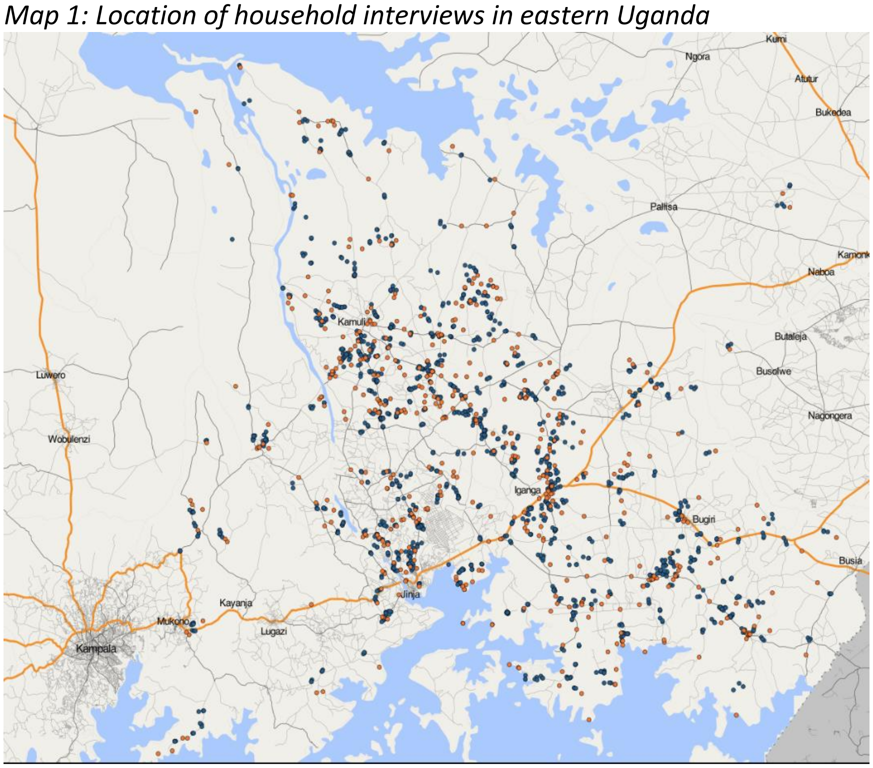
Metric Measurement

This evaluation relied on self-reported measures for lighting usage, time spent on productive activities, and health. Direct observation might have provided more accurate data, but was not feasible due to cost and intrusiveness. We have no reason to believe the self-reports were biased, and most studies on the impact of solar lighting use similar methods.

IV. Respondent Household Characteristics

This study surveyed households predominantly in rural eastern Uganda (see Map 1). The following statistics describe both d.light and comparison households included in the study. A large majority of respondent households reside in a rural setting (85%),[xxiii] and on average have 6.0 members, including 2.1 children in primary school and 1.2 children age five or younger. Nearly half of all household heads reported at least some primary education as their highest level of education attained (49%), while 39% reported some secondary education as their highest level of education. Household heads are primarily farmers (42%) or self-employed in small businesses (38%) such as motorcycle taxi driving.

Map 1: Location of household interviews in eastern Uganda



Orange dots represent d.light customers and blue dots represent comparison households. Some comparison households may be obscured due to close proximity.

Picture 1: d.light customer's home

The front room of a d.light customer's house. The motorcycle helmets on the tables belong to the survey field staff, not the household. Note the d.light lantern, light bulb switch, and wiring on the shelves in the back of the room.

Just over half the households (52%) are estimated as living under the $2.50 per person per day poverty line (2005 PPP).[xxiv] Household consumption expenditure, as a proxy for income, is estimated at an average $2.12 (2014 USD) per day,[xxv] or $774 USD per year. Note that d.light and comparison households are somewhat less poor than the average Ugandan household, of which 71% live below the $2.50/day per capita poverty line.[xxvi] These figures are consistent with expectations around early adopters of new technologies, who are usually not the truly poorest populations.

Picture 2: Lighting products in rural Uganda

These photos were taken during the impact evaluation survey and depict the mix of typical baseline lighting sources of households in the D20g go-to-market pilot area. From left to right, the photo above shows a “paraffin lantern” (large, hurricane-type kerosene lantern), a “tadooba” (effectively a kerosene candle, welded together out of scrap metal with a cloth wick), and a battery-driven LED lantern.

The vast majority of households (75%) use self-collected biomass for cooking fuel, and the predominant lighting sources at baseline were kerosene-fueled products (tadooba or paraffin lantern; 50%) and battery-powered flashlights (31%). The prevalence of these lighting sources is consistent across all income levels, meaning that even relatively wealthier households in the market area rely heavily on kerosene. Specifically, dirty, low-output kerosene candle tadoobas (see Picture 2) were the primary lighting source across all income levels except for the top third in the sample, in which the prevalence of flashlights and LED lights is slightly higher.[xxvii] In general, households use a mix of multiple low-quality lighting sources to meet their daily lighting needs: typically 2 or 3 different types of products in a given day.

See Tables 2-7 in Appendix B for more details.

V. Impact Evaluation Results

All impact estimates reported below are statistically significant at the 5% level, unless otherwise noted. Note that these findings apply specifically to the context of this study; as with any study, caution should be taken not to overgeneralize outside the scope of the study's demographic, geography, and solar product.

Lighting usage

For the purposes of this report, low-quality lighting sources include tadooba (kerosene candles, see Picture 2), kerosene lanterns, flashlights and other battery-driven lights (referred to together as just "flashlights" in the rest of this report), and wax candles. High-quality lighting sources are categorized as electric light from a solar system or lantern or a fixed electric light source powered by electricity or a generator. These are sources that give off electric light, rather than a flame which is less bright and produces fumes, and typically in a greater quantity than a flashlight.[xxviii]

In general, d.light households significantly reduced usage of baseline low quality lighting sources with the D20g. The proportion of d.light households whose primary lighting source[xxix] was kerosene-based[xxx] dropped from 47% to 8% and of flashlights from 32% to 5% after D20g purchase.[xxxi] In contrast, comparison households' use of kerosene and flashlights as primary sources remained relatively constant, going from 53% to 57% and 30% to 22%, respectively. d.light households experienced a statistically significant decrease—by roughly half—in the number of flashlights, paraffin lanterns, and tadoobas[xxxii] used by endline. However, only 28.4% of d.light households reported having used *only* their d.light system for lighting in the past three months, indicating that most houses do not eliminate all other lighting sources after acquiring a D20g, at least within the 6 month horizon of this evaluation.

In terms of the quantity of light accessed, d.light households consumed fewer hours of low quality light and more hours of high quality light than comparison households, for a net result of 2.9 additional hours of lighting per day, an increase of 29%—representing major gains in the quality and quantity of household lighting. This stems from an increase of *6.2* additional hours of high-quality light (*+157%*) and a decrease of *4.3* fewer hours of low-quality light (*-63%*).[xxxiii]

See Tables 8-11 in Appendix B for more details.

Productive time

Despite regular usage of the D20g and resultant gains in light quantity and quality, the data showed that owning a D20g did not have a statistically significant impact on the amount of time household members spent carrying out chores, engaging in income generating work, or studying.

Outside of these activities, the survey did not capture how many hours people spent on other activities, including leisure activities. However, 50% of d.light households report keeping at least one D20g bulb on as a security light overnight, which many households with either electricity or a different solar system do as well. As such, it is likely but unproven that a large part of this increase in hours of lighting used is due to use of D20g bulbs as security lights at night.

While the number of hours spent on chores, income generating activities, and studying did not change, it may be the case that even with more hours of high quality lighting available, people do not have the need or desire to spend more time than they already were on these activities. It is also possible that having high quality of light in the evening allowed d.light households to shift the time they engaged in certain activities to the evening hours, which could have freed up more time for other activities during the daylight hours.[xxxiv] However, this study did not collect data on how many hours people used lighting sources for these activities, nor on time spent on these activities during the day versus at night, and thus cannot definitively account for what households use their increased lighting hours for. Additionally, this study only covered a range of six to seven months, and it is possible that behavior change and productivity gains stemming from increased light availability take longer to be realized.

Aside from the lack of gains in number of hours spent on chores, income generating activities, and studying, it is possible that by carrying out these activities using a higher quality lighting source, d.light households might have experienced productivity gains that were not captured in this study.

See Tables 12-13 in Appendix B for more details.

Energy expenditure outcomes[xxxv]

At baseline, d.light households spent $1.03 per week on lighting—primarily on low-quality lighting sources ($0.84)—and $0.37 on mobile phone charging-related expenses, for an annual energy expenditure of $74.[xxxvi] This figure represents an estimated 13% of a household's overall consumption.[xxxvii,xxxviii]

Table 1: Impact of owning a d.light D20g system on weekly household energy expenditure and income

Household energy outcome	*N of obs.*	*Treatment effect (95% CI)*	*Treatment effect % (95% CI)*
Total lighting expenditure (excluding cost of d.light D20g for d.light households at endline)	776	**-$0.77*** (-$1.28, -$0.26)	-50.7%* (-84.2%, -17.1%)
Expenditure on low-quality lighting sources	812	**-$0.58*** (-$0.86, -$0.30)	-58.0%* (-86.0%, -30.0%)
Expenditure on high-quality	894	**-$0.21**	-40.4%

lighting sources (excluding cost of d.light D20g for d.light households at endline)		(-$0.64, $0.22)	(-123.1%, 42.3%)
Net phone charging-related expenditure (expenditure – income)	934	**-$0.47*** (-$0.62, -$0.32)	-188.0%* (-248.0%, -128.0%)
Phone charging expenditure	934	**-$0.31*** (-$0.37, -$0.25)	-83.8%* (-100.0%, -67.6%)
Phone charging income	934	**$0.16*** ($0.03, $0.29)	123.1%* (23.1%, 223.1%)
Expenditure on trips made exclusively to purchase fuel for lighting or to charge phones	932	**-$0.13*** (-$0.19, -$0.07)	-92.9%* (-135.7%, -50.0%)
Net energy expenditure in Year 1 of D20g ownership	776	**$2.99*** ($2.45, $3.53)	154.1%* (126.3%, 182.0%)
Net energy expenditure in Year 2 of D20g ownership and subsequent years	776	**-$1.41*** (-$1.95, -$0.87)	-72.7%* (-100.5%, -44.8%)
Impact on energy expenditure outcomes. Please see Table 14 in Appendix B for more details.			

A financed D20g costs approximately $230 in Uganda: households make a deposit of approximately $30, and pay approximately $0.60 per day over the course of a year. Assuming households pay off the D20g system in one year,[xxxix] d.light households spend $156 more than they would have without the D20g purchase in their first year of ownership.[xl] Broken down into components, d.light households do save money relative to comparison households on non-D20g lighting expenditure ($0.77 weekly), phone charging ($0.47, which also accounts for income made charging other people's phones), and expenditure on trips to purchase lighting fuel or charge phones ($0.13), but these savings are offset by the overall cost of the D20g system and increased lighting usage.

Assuming that d.light households continue their lighting and phone charging behavior in subsequent years, and assuming the durability of the d.light system and its battery, they should be able to save money in the long run. After customers pay off the cost of the system in Year 1, d.light households would save $1.41 weekly on energy expenditures for the rest of the product's life (estimated at 5-10 years),[xli] spending 73% less than comparison households. Energy expenditures would drop to just 3% of overall household consumption, compared to 13% at baseline. [xlii] As such, d.light households stand to save on average $74 each subsequent year, recovering the cost of the D20g system in 3.1 years.[xliii] Please see Figure 2 in Appendix B for a visualization of savings over time.

While these findings are relevant for the D20g financed home systems in Uganda, this metric may vary particularly for pico solar products. Generally, pico solar are paid for upfront with a much shorter payback period. Hence, further research would allow us to understand the difference between energy expenditure and savings between customers who purchased pico solar products versus those that purchased financed solar home systems.

See Table 14 and Figures 1-2 in Appendix B for more details.

Other socioeconomic outcomes

In addition to energy expenditures, the evaluation also investigated several other socioeconomic outcomes: self-reported wealth, self-reported social status, daily household consumption as estimated by the USAID Poverty Assessment Tool, and ownership of several household assets.

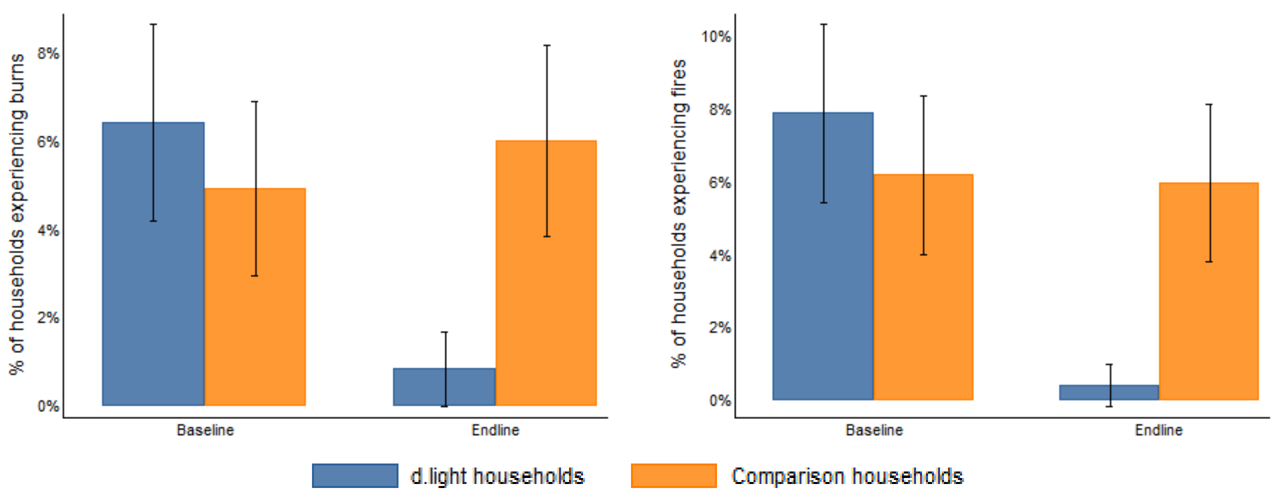
No statistically significant impact was found on self-reported wealth or self-reported social status. While both these self-reported outcomes were slightly higher for d.light households than for comparison households, they were higher at both baseline and endline, with no significant relative change from baseline to endline. There was also no statistically significant impact found on estimated daily household consumption.

If the initial increase in energy expenditure due to the D20g purchase were so large that it placed a financial burden on households purchasing the system, a decrease in savings would be expected. To test this, change in ownership of easily liquidated assets like livestock and small household equipment was analyzed as a proxy for shorter-term changes in financial status, since households in the developing world often keep their savings in physical assets. Analysis shows there was no impact on these assets for d.light households.

See Tables 15-16 in Appendix B for more details.

Health & personal safety outcomes

Figures 1a, 1b: Impact of owning a d.light D20g system on burns and fires



These graphs depict, for d.light and comparison households, the baseline and endline means of the proportion of households who reported having experienced burns or fires in the preceding months. The error bars represent the 95% confidence interval. At baseline, households were asked about the last six months; at endline, they were asked about the last three months.

Note that subtracting the difference from baseline to endline of the comparison households from the difference from baseline to endline of the d.light households will not exactly yield the treatment effect estimates given in Table 16 of

Appendix B. This is because the treatment effect estimates also control for several household characteristics.

In comparison to fossil fuel-burning light sources, such as open-flame tadoobas and kerosene lanterns, electric light sources such as the d.light system neither emit fumes nor have flame, potentially decreasing indoor air pollution and fire risks. Hence, there is reason to believe a priori that reducing the quantity of fossil fuels burnt indoors could improve health outcomes.

Study results showed that d.light households experienced significantly fewer burns from lighting sources, 88% fewer than those that had not bought the D20g (with an estimated reduction in prevalence of 6.4 percentage points). d.light households also experienced significantly fewer fires caused by lighting sources, 93% fewer households than if they had not bought the D20g (an estimated 6.0 percentage point reduction in prevalence). At endline only 0.9% of d.light households experienced burns and 0.4% experienced fires. See Figures 1a and 1b for a visualization of these results.

There was no statistically significant impact found on self-reported personal health. However, there is evidence that prevalence of coughing is lower among d.light households; coughing decreased by 8.5 percentage points, a result that is not statistically significant, but is very close to being significant (p=0.052). We acknowledge that self-reported personal health is only one way to report health outcomes which might not encompass the totality of health outcomes of interest. Further research could look into additional effective techniques to measure personal health changes over time, such as spirometers to measure effects on lungs due to reduced indoor air pollution from kerosene lanterns.

See Table 16 in Appendix B for more details.

VI. D20G CUSTOMER USE & SATISFACTION

The vast majority of d.light households reported that they typically use the system daily, excepting any technical or payment problems (92%).[xliv] 90.5% of d.light households reported using the D20g in the three months before being surveyed, and 70% reported using the system in the past 24 hours.

The top four reported motivations for purchasing the D20g were:

1. general home lighting (45%)
2. economic benefits (44%)
3. health and safety reasons (fumes, fires; 37%)
4. phone charging (34%).

Only 14% report using the D20g in their business or place of work.

Customers on average reported high satisfaction levels: 49% of customers reported a satisfaction of 8 or higher on a 1-10 scale, with an average of 7. Similarly, 70% reported that their overall happiness with their home “improved a lot” as a result of the D20g, specifically due to better quality light (27%), more hours of lighting (24%), and not needing to buy lighting fuel (19%). Nearly all customers (97%) have recommended purchasing a D20g to friends or family.

See Tables 17-20 and Figure 3 in Appendix B for more details.

VII. Conclusion

More than one billion people lack electricity around the world, mostly in Africa and Asia. The International Energy Agency estimates it will cost $700 billion dollars to achieve universal energy access by 2035[xlv] by building out the electrical grid, excluding the supply and service improvements that would be required. At present there are no plans to move in this direction. Solar and other renewable energies provide an alternative and more feasible method of connecting many of those without access to energy with high quality light and other services. Renewable solar energy technology can be harnessed by many base-of-the-pyramid households for lighting and small appliance power needs without exceeding average energy expenditures.

Solar products are increasing in prominence among rural households in developing countries, as evidenced by the introduction of d.light and competitors into Uganda. Results of this study show that owning the D20g solar home system has positive impact on quantity and quality of light, expected long term savings and fewer burns and fires.

Yet the results are mixed when it comes to short term financial impact, productive time, and self-reported health. Owners of the D20g express a high degree of satisfaction with the system and pleasure in being able to reduce kerosene usage. However, there does not appear to be an increase in productivity that results from ownership of a home system over six months–neither from an increase in income generating work nor in study time of students. Households did not report any change in wealth, socio-economic status or self-perceived health.

Next Steps

While this evaluation measured the impact of the D20g solar home system over a 6-7 month time horizon, the D20g system is intended to last between five and ten years. It would be worthwhile to measure results of the system several years in the future to identify the durability of the D20g in real world conditions, if and how usage and other trends outlined above change, and whether these impact results hold over a longer time period.

These findings also raise a number of related topics that warrant further in-depth research, as well as additional research that could either corroborate or shed new light on outcome areas reported in this study. d.light will work with its partners in the off-grid lighting sector to research these questions, including:

- Does using higher quality of light affect productivity?
- What are the environmental impacts of the increased quantity of improved lighting?

- How do these findings compare to the impact of pico solar?
- Why do households not fully displace their baseline lighting sources—is it because of a desire for as much light as possible given all available resources?
- Does usage of (and resultant spending on) these baseline sources diminish over a longer period of time?
- Do behaviors related to use of lighting sources for productive activities change over time periods longer than six months?
- Does the use of the light for security improve perceptions of safety?
- How could we further measure customer satisfaction, for example using a net promoter score or Constituent Voice?

In the meantime, d.light will review the assumptions that underlie its current theory of change and the data points that inform specific impact metrics. That analysis, along with findings from this report, will be used to revise d.light's impact metrics and to design products that meet the needs of an increasing number of consumers without access to the energy grid. We think that this study is an important addition to the industry's body of research which speaks to proof of impact; however, we think this is just the beginning. The findings on productivity, energy expenditure and health indicate that further research is needed to truly understand what is happening in customers' households. It will also be crucial for d.light and the industry to further investigate the differences in impact between home systems and pico solar. With support from our partners, we hope to continue our commitment to further rigorous study of impact to build upon these findings to further illuminate the impact of our products in Uganda and beyond.

VIII. Appendices

Appendix A: Terminology and definitions used in this report

Many tables in this report give summary statistics on a number of outcomes. Terms used in this paper to describe the data are bolded below, followed by their definitions.

- The **number of observations or households (N**) listed for each statistic refers to the number of households whose data were included in calculating the specified statistic. Since 971 combined d.light and comparison households were interviewed at endline, this represents the maximum number of observations for any given table.[xlvi]
- The **mean** is the average value for a particular variable or calculation in this study's sample of households. The mean value of the sample is therefore an estimate of the "true" mean in the entire population of d.light D20g purchaser and comparison households.
- While the mean in our sample of households that purchased a d.light D20g system (i.e. the treatment group, referred to throughout the report as **d.light households**) is usually a close estimate of the mean value of the entire population under evaluation (i.e. all d.light households that have purchased a d.light D20g system in the pilot area of Uganda) there is always some statistical uncertainty about how close this sample mean is to the true value for the larger population of d.light customers, as the study's sample only includes a fraction of all possible households. (The same is true for the comparison group). To account for this uncertainty, mean values are displayed in the tables below with a **95% confidence interval (CI)**. The confidence interval specifies a range of values that is highly likely to contain the true population value that is being estimated. Specifically, if samplings of the same number of households as in our survey were repeated many times from the same population, then 95% of the samples will produce a confidence interval that contains the true population value.
- The **median**, or middle value when all households' values are sorted, also gives a sense of the typical value for an outcome. A mean significantly greater (less) than the median may indicate that the outcome's distribution is right-skewed (left-skewed), or that there are some values that are much larger (smaller) than where most of the values lie.
- The **standard deviation** (square root of the average squared distance from the mean) gives a sense of how much variability there is amongst household values. The standard deviation is a descriptive statistic of the spread of the values of the variable in the data. Values that are clustered around a particular point generate smaller standard deviations, while values that are very spread out from each other generate larger standard deviations. The greater the variability of values among households—and thus the larger the standard deviation—the less precise our estimate of the true population value will be, and the more difficult it is to determine if there is a real (i.e. statistically significant) difference between two values. See the section below for more detail on statistical significance.
- The **minimum** and **maximum** are the minimum and maximum values of household observations for that outcome, and give the full range of the outcome values reported through the survey.

Estimation of impact

- Estimation of the impact of owning a d.light D20g system is done using difference-in-differences analysis and simple differences analysis. **Difference-in-differences analysis** compares the change in outcome over time (i.e. from baseline to endline) between the treatment group—in our case, the d.light households—and comparison group. By comparing the d.light households' change in outcome over time to the comparison households', the effect of the d.light D20g system on the d.light households' outcome can be isolated from other changes in outcome they might have experienced even without the d.light D20g system.
- Several outcomes included in this report only have endline data; for these outcomes, **simple differences analysis** is used to compare the d.light households' and comparison households' outcomes at endline.
- Both types of analysis yield an estimate of the **treatment effect** on the outcome due to owning a d.light D20g system. This is the estimated value of change that was caused by owning a d.light D20g system. The results tables in this report include means of the outcome measure for both d.light and comparison households at baseline and at endline, and the estimated treatment effect. Because the treatment effect estimate also controls for slight differences among a number of household characteristics identified during the matching process (listed in Appendix A), the treatment effect cannot be obtained simply by subtracting the change in comparison households' mean over time from that of the d.light households'. All estimates of treatment effect are presented with a 95% confidence interval (see above for definition).
- A treatment effect is said to be **statistically significant at the 95% level** if its 95% confidence interval does not include zero. This indicates that the treatment effect is likely to be non-zero (either positive or negative). **Statistically significant treatment effects at the 95% level are marked with an asterisk (*) in all results tables**.
- All results tables also give the treatment effect as a percentage of a calculated comparison value, labeled as "**treatment effect %**." This percentage is calculated as the treatment effect divided by the mean value of the outcome at endline for d.light households less the treatment effect. The mean value of the outcome at endline for d.light households minus the treatment effect reflects the hypothetical value of the outcome at endline for the d.light households, had they not "received treatment"—in this case purchased the D20g. As such, the treatment effect % is effectively the estimated percentage change in the outcome for d.light households due to owning the D20g system.

Other standards used in this report

For the purposes of this report, **low-quality lighting sources** include tadooba (kerosene candles, see Picture 2), kerosene lanterns, flashlights and other battery-driven lights (referred to together as just "flashlights" in the rest of this report), and wax candles. **High-quality lighting sources are** categorized as electric light from a solar system or lantern or a fixed electric light source powered by electricity or a generator.[xlvii] Within the tables included below, "other low-quality lighting sources" include hand-made battery-driven lights and built-in LED lights on cell phones, and "other high-quality lighting sources" include electric lights powered by generators or inverters.

This report uses two means of reporting monetary values. All household expenditures and income are expressed in **current (2014) US dollars**. Amounts reported in Ugandan shillings are converted at a rate of 2500 UGX = $1 USD.[xlviii]

Poverty lines are expressed in terms of **2005 purchasing power parity (PPP)**, which controls for differing purchasing power of currencies to purchase goods. This is a common way of comparing economic circumstances of individuals in different parts of the world based on the amount and types of goods and services they can purchase, regardless of what the actual prices are. The conversion rate between 2005 PPP and 2014 USD is $1.91 2005 PPP = $1 2014 USD.

Several questions asked respondents to rate themselves on a scale from 1 to 10 with regards to wealth, social status, and personal health. Respondents were shown a ladder with rungs numbered 1 to 10 from bottom to top, and asked where on the ladder they saw themselves relative to the rest of their village.[xlix]

Note that the results displayed below represent all d.light households, even though some of them were not actively using the d.light home system during the time of the endline interview for various reasons. Approximately 30% of d.light households had not used the D20g system in the 24 hours prior to being surveyed and 9% had not used the D20g system in the previous three months. (See Table 8 in Appendix B for more details.)

Appendix B: Accompanying tables

I. Respondent Household Characteristics

Table 2: Household profile

Household variable	*Mean (95% CI)*	*Median*	*Std Dev*	*Min*	*Max*
Household size	6.04 (5.85, 6.23)	6	3.07	1	27
Members age 5 or under	1.21 (1.14, 1.28)	1	1.14	0	6
Members ages 6-18	2.57 (2.43, 2.71)	2	2.24	0	15
Members attending primary school (ages 6-18)	2.06 (1.94, 2.18)	2	1.91	0	14
Members attending secondary school (ages 12-18)	0.31 (0.27, 0.35)	0	0.64	0	5
Likelihood of being under Ugandan nat'l poverty line (about $0.56/day per capita)	4.0% (3.7%, 4.3%)	-	-	-	-
Likelihood of being under $1.25 (2005 PPP)/day per capita poverty line	13.2% (12.4%, 14.0%)	-	-	-	-
Likelihood of being under $2.50 (2005 PPP)/day per capita poverty line	52.3% (50.7%, 53.9%)	-	-	-	-
Daily household consumption (2014 USD)	$2.12 ($2.01, $2.23)	$2.03	$1.07	$0.38	$4.97

These data are for N=971 households (comparison and d.light households combined), except for daily household consumption, which is for N=382 households (because the questions necessary for this estimate were added partway through endline surveying, and the top and bottom 5% of outliers were removed here so that extreme values would not bias the results).

Likelihood of being under each poverty line is estimated using the Progress out of Poverty Indicator (PPI), a short, 10-question survey developed by the Grameen Foundation that gauges the likelihood a household lives below certain poverty thresholds based on asset ownership and other household characteristics.

Note that d.light and comparison households are somewhat less poor than the average Ugandan household, of which 19%, 35% and 71% live below each of the poverty lines included in the table below (respectively).[l]

The daily household consumption is estimated using the Poverty Assessment Tool (PAT), developed by USAID to estimate the daily consumption of surveyed households. Consumption refers to expenditure on goods and services that will be used directly by the household, and excludes expenditure on savings and investment. The survey consists of a household roster and nine additional questions. It takes longer to administer than the PPI, but also relatively expedient compared to traditional income surveys.

Note that there is a discrepancy in the estimates of household consumption, based on the PPI poverty line estimates and the PAT household consumption estimates: converted into the same units the poverty lines use, the PAT estimates mean per capita consumption to be $0.96 2005 PPP. The two estimates are made using two different poverty assessment tools (the PPI and PAT), which in turn were developed using different sources of data. However, for households in this study, there is a positive correlation between household consumption as estimated by the PAT and the household's socioeconomic level estimated by the PPI.

Table 3: Household location

Setting	*% of households*
Rural	85.1%
Semi-urban	13.0%
Urban	2.0%
These data are for N=971 households, from baseline. Urban refers to major cities (mainly the cities of Jinja, Iganga, and Kamuli). Semi-urban refers to towns that are smaller than these major cities. Rural includes households who live in small local trading centers, which typically consist of one street of small stores, and households in less dense areas.	

Table 4: Highest level of education of household head

Education level	*% of households*
No education	5.7%
Primary education	49.3%
Secondary education	38.5%
Tertiary education	6.6%
These data are for N=938 households (comparison and d.light households combined). A household head is categorized under primary, secondary, or tertiary education if he or she has completed any years of primary, secondary, or tertiary education respectively.	

Table 5: Occupation of household head

Occupation	*% of households*
Farmer	19.0%
Subsistence farmer	23.2%
Farm wage laborer	2.9%
Professional	12.4%
Self-employed	38.4%
Boda boda driver	6.1%
Shopkeeper	4.9%
Produce seller	3.0%
Other self-employed	24.3%
Not looking for work	2.6%
Looking for work	0.2%
Other	1.2%
These data are for N=968 households (comparison and d.light households combined). A boda boda is a for-hire motorcycle taxi. Other self-employed includes technical trades, cash crop business, fishing, and building.	

Table 6: Main cooking fuel used

Cooking fuel type	*% of households*
Leaves/husk/cow dung collected by household	3.7%
Leaves/husk/cow dung purchased by household	1.2%
Wood/bamboo/sawdust collected by household	71.3%
Wood/bamboo/sawdust purchased by household	9.3%
Charcoal	14.0%
Kerosene or gas cylinder	0.5%
These data are for N=428 households (comparison and d.light households). The question providing this data was added partway through endline surveying.	

Table 7: Baseline primary lighting source by baseline Progress out of Poverty Indicator (PPI) score

Lighting source		*Bottom third by PPI score (N=321)*		*Middle third by PPI score (N=320)*		*Top third by PPI score (N=269)*	
Low-quality	Tadooba	55.1%	**97.2%**	48.4%	**90.9%**	24.5%	**73.2%**
	Flashlight	37.1%		33.1%		28.3%	
	Paraffin lantern	3.7%		6.9%		19.3%	
	Other low-quality	1.2%		2.5%		1.1%	
High-quality	Non-D20g solar	2.5%	**2.8%**	6.9%	**9.1%**	15.2%	**26.8%**
	Electricity	0.3%		1.9%		11.5%	
	Other high-quality	0.0%		0.3%		0.0%	

These data are for N=910 households total.

At baseline, primary lighting source was defined as the source each household reported using for the most number of hours.

The PPI score estimates the likelihood that a household is under a poverty line; the breakdown of households into three groups by their PPI score roughly reflects the poorest third, middle third, and wealthiest third of households surveyed. Average likelihoods of being under \$2.50 (2005 PPP)/day per capita poverty line at baseline, for each baseline PPI score division, are 77.9%, 54.0%, and 26.7% respectively.

The numbers in bold represent the total proportion of comparison or d.light households who reported a lighting source within the overall low-quality or high-quality categories.

II. Impact Evaluation Outcomes

a) Lighting usage outcomes

Table 8: Lighting source usage

Lighting source – Baseline		*d.light households (N=483)*						*Comparison households (N=488)*					
		Last 3 months		*Last 24 hours*		*Primary source*		*Last 3 months*		*Last 24 hours*		*Primary source*	
Low-quality	Tadooba	70.4%		54.9%		37.5%		71.3%		65.2%		44.5%	
	Flashlight	61.7%		45.5%		32.1%		60.2%		49.6%		29.9%	
	Paraffin lantern	36.0%	**96.3%**	15.1%	**77.4%**	9.3%	**80.5%**	36.1%	**96.1%**	16.2%	**88.3%**	8.4%	**83.2%**
	Wax candle	6.8%		-		-		10.5%		-		-	
	Other low-quality	8.1%		5.2%		1.7%		6.4%		4.1%		0.4%	
High-quality	Non-D20g solar	12.6%		8.9%		6.6%		12.1%		10.2%		8.0%	
	Electricity	2.7%	**16.8%**	1.7%	**10.6%**	2.5%	**9.1%**	6.6%	**18.9%**	5.1%	**15.4%**	5.3%	**13.3%**
	Other high-quality	1.9%		0.0%		-		1.0%		0.2%		-	
Lighting source – Endline		*d.light households (N=483)*						*Comparison households (N=488)*					
		Last 3 months		*Last 24 hours*		*Primary source*		*Last 3 months*		*Last 24 hours*		*Primary source*	
Low-quality	Tadooba	34.2%		23.4%		7.0%		74.4%		65.8%		46.7%	
	Flashlight	39.5%		29.4%		5.0%		60.9%		52.5%		22.1%	
	Paraffin lantern	14.3%	**66.5%**	5.0%	**47.8%**	0.8%	**13.7%**	31.8%	**96.7%**	17.2%	**90.4%**	9.6%	**80.5%**
	Wax candle	5.6%		1.0%		0.4%		8.4%		1.4%		0.4%	
	Other low-quality	3.3%		3.9%		0.4%		6.4%		7.0%		1.6%	
High-quality	d.light D20g system	90.5%		69.8%		79.7%		-		-		-	
	Non-D20g solar	7.5%	**92.8%**	6.2%	**75.2%**	3.3%	**86.3%**	10.5%	**22.7%**	9.6%	**20.7%**	7.4%	**19.3%**
	Electricity	3.9%		3.1%		3.3%		12.3%		11.1%		11.3%	
	Other high-quality	0.8%		0.2%		0.0%		1.4%		0.4%		0.6%	

At baseline, primary lighting source is determined by which source each household reported using for the most number of hours. Because there are several households who did not report data on their usage of some lighting sources, the percentages for primary sources do not add up to 100%. At endline, primary lighting source was directly self-reported by respondents.

The numbers in bold represent the total proportion of each household group that reported a lighting source within the overall low-quality or high-quality categories.

Table 9: Number of lighting source units owned by households at endline

# of units - d.light households	*Tadooba*	*Flashlights*	*Low-quality Paraffin lanterns*	*Wax candles*	*Other low-quality*	*High-quality d.light solar bulbs*	*Non-D20g solar system bulbs*	*Non-D20g solar lanterns*	*Electricity bulbs*
0	65.8%	60.6%	85.9%	95.2%	96.9%	10.8%	96.5%	97.3%	96.9%
1	23.0%	28.0%	11.2%	4.6%	2.5%	2.1%	1.0%	2.7%	0.0%
2	8.3%	8.7%	2.1%	0.2%	0.4%	83.4%	1.4%	0.0%	0.8%
3	2.1%	1.7%	0.6%	0.0%	0.2%	1.9%	0.4%	0.0%	0.8%
4	0.4%	1.0%	0.2%	0.0%	0.0%	1.9%	0.4%	0.0%	0.4%
5 or more	0.4%	0.0%	0.0%	0.0%	0.0%	-	0.2%	0.0%	1.0%
# of units - Comparison households	*Tadooba*	*Flashlights*	*Low-quality Paraffin lanterns*	*Wax candles*	*Other low-quality*	*High-quality* -	*Non-D20g solar system bulbs*	*Non-D20g solar lanterns*	*Electricity bulbs*
0	26.2%	40.0%	68.2%	93.6%	93.6%	-	92.6%	97.7%	88.9%
1	40.0%	39.2%	23.4%	5.7%	5.9%	-	1.6%	2.0%	0.4%
2	26.0%	13.3%	6.8%	0.6%	0.4%	-	1.8%	0.2%	1.0%
3	6.8%	4.5%	1.4%	0.0%	0.0%	-	2.0%	0.0%	1.8%
4	0.8%	2.5%	0.2%	0.0%	0.0%	-	0.6%	0.0%	2.7%
5 or more	0.2%	0.4%	0.0%	0.0%	0.0%	-	1.2%	0.0%	5.1%

These data are for N=483 d.light households and N=488 comparison households (except for flashlights, which has N=482 d.light households and N=487 comparison households, and other low-quality d.light households which has N=482).

Data reported here is for the number of units of a given lighting source a household owns. This number is non-zero if they reported using the source in the last 3 months, *except* for non-D20g solar system bulbs, non-D20g solar lanterns, and electricity bulbs, which is non-zero if they reported using the source in the last 24 hours. Households who reported not using the specified source in the given time period are recorded as owning zero units of the source. (Thus, d.light households who did not use the D20g system in the last 3 months are listed as using 0 D20g bulbs.) Note that these figures may underestimate the number of products owned, as households may own products they have not actually used in the past 3 months.

Table 10: Impact of owning a d.light D20g system on units of lighting sources used

Lighting source	*N of obs.*		*Baseline mean (95% conf int)*	*Endline mean (95% conf int)*	*Treatment effect (95% conf int)*	*Treatment effect % (95% conf int)*
Flashlights	930	d.light	0.98 (0.88, 1.08)	0.54 (0.47, 0.61)	**-0.42*** (-0.58, -0.26)	-43.8%* (-60.4%, -27.1%)
		Comp.	0.87 (0.78, 0.96)	0.90 (0.81, 0.99)		
Paraffin lanterns	934	d.light	0.44 (0.38, 0.50)	0.17 (0.13, 0.21)	**-0.22*** (-0.31, -0.13)	-56.4%* (-79.5%, -33.3%)
		Comp.	0.46 (0.40, 0.52)	0.42 (0.36, 0.48)		
Tadooba	934	d.light	-	0.49 (0.41, 0.57)	**-0.61*** (-0.73, -0.49)	-55.5%* (-66.4%, -44.5%)
		Comp.	-	1.16 (1.08, 1.24)		

Only flashlights, paraffin lanterns, and tadooba are included here. Baseline data on number of units owned was collected only for flashlights and paraffin lanterns, and so difference-in-difference analysis can only be done for these two sources. A simple differences analysis for number of tadooba was added to give complete information on kerosene products. Households who reported not using the specified source in the past three months are recorded as owning zero units of the source; in reality however, households may own additional units that they do not use.

Table 11: Impact of owning a d.light D20g system on hours of lighting used daily

Hours used daily, by lighting source	*N of obs.*		*Baseline mean (95% CI)*	*Endline mean (95% CI)*	*Treatment effect (95% CI)*	*Treatment effect % (95% CI)*
Low-quality lighting source	714	d.light	6.53 (5.67, 7.39)	2.56 (2.07, 3.05)	**-4.29*** (-5.72, -2.86)	-62.6%* (-83.5%, -41.8%)
		Comp.	7.01 (6.24, 7.78)	7.34 (6.60, 8.08)		
Tadooba	874	d.light	2.79 (2.36, 3.22)	1.14 (0.85, 1.43)	**-2.36*** (-3.06, -1.66)	-67.4%* (-87.4%, -47.4%)
		Comp.	2.95 (2.62, 3.28)	3.59 (3.16, 4.02)		
Flashlight	890	d.light	2.85 (2.26, 3.44)	1.11 (0.84, 1.38)	**-1.17*** (-2.08, -0.26)	-51.3%* (-91.2%, -11.4%)
		Comp.	2.93 (2.44, 3.42)	2.60 (2.15, 3.05)		
Paraffin lantern	926	d.light	0.83 (0.59, 1.07)	0.20 (0.10, 0.30)	**-0.54*** (-0.97, -0.11)	-73.0%* (-131.1%, -14.9%)
		Comp.	0.87 (0.58, 1.16)	0.70 (0.51, 0.89)		
Other low-quality	810	d.light	0.07 (-0.01, 0.15)	0.08 (0.00, 0.16)	**-0.13** (-0.34, 0.08)	-61.9% (-161.9%, 38.1%)
		Comp.	0.05 (-0.01, 0.11)	0.21 (0.05, 0.37)		
High-quality lighting source	788	d.light	0.57 (0.36, 0.78)	10.22 (9.19, 11.25)	**6.24*** (4.62, 7.86)	156.8%* (116.1%, 197.5%)
		Comp.	1.07 (0.77, 1.37)	4.11 (2.98, 5.24)		
All lighting sources	608	d.light	7.09 (6.10, 8.08)	13.09 (11.91, 14.27)	**2.94*** (0.51, 5.37)	29.0%* (5.0%, 52.9%)
		Comp.	8.36 (7.50, 9.22)	11.61 (10.24, 12.98)		

Because some households may have complete data on all low-quality (or all high-quality) lighting sources, but may not have reported data on lighting sources in the other category, the number of observations included in the analysis for all lighting sources is lower than it is for the low-quality and high-quality lighting source analysis.

IDinsight tested various tadoobas and lanterns and measured that one hour of lantern usage goes through 25.6 mL of kerosene, and one hour of tadooba usage goes through 13.825 mL.

b) Productive time outcomes

Table 12: Impact of owning a d.light D20g system on daily productive time of household members

Daily productive time (hours per relevant household member, per day)	*N of obs.*		*Baseline mean (95% CI)*	*Endline mean (95% CI)*	*Treatment effect (95% CI)*	*Treatment effect % (95% CI)*
Chores	934	d.light	2.93 (2.78, 3.08)	2.87 (2.73, 3.01)	**-0.07** (-0.38, 0.24)	-2.4% (-12.9%, 8.2%)
		Comp.	3.02 (2.88, 3.16)	3.06 (2.91, 3.21)		
Income-generating activities	934	d.light	3.87 (3.59, 4.15)	3.51 (3.22, 3.80)	**-0.24** (-0.69, 0.21)	-6.4% (-18.4%, 5.6%)
		Comp.	3.46 (3.21, 3.71)	3.26 (2.99, 3.53)		
Studying, general	572	d.light	0.73 (0.64, 0.82)	0.83 (0.73, 0.93)	**0.04** (-0.15, 0.23)	5.1% (-19.0%, 29.1%)
		Comp.	0.70 (0.61, 0.79)	0.71 (0.63, 0.79)		
Studying, high-intensity period	430	d.light	-	1.06 (0.94, 1.18)	**0.03** (-0.19, 0.25)	2.9% (-18.4%, 24.3%)
		Comp.	-	1.05 (0.92, 1.18)		

The number of hours spent on each productive activity is calculated by averaging the total reported hours across relevant household members in each household. Chores (cooking, washing, cleaning) account for all household members over the age of 3 years (5.47 people per household at baseline), income-generating activities for all household members over the age of 10 years (3.85 people at baseline), and studying for all members ages 6-18 attending school (3.3 people at baseline). The number of people participating in each activity did not change at endline in practical or statistical terms.

The general studying outcome data comes from asking students in households how many hours they studied the previous night during baseline and endline surveying. However, because both the baseline and endline surveys took several months to complete, the studying data collected during surveying spans a wide range of low- and high-intensity studying periods in the school year. To obtain data on studying during a more consistently higher-intensity period of the school year, phone calls were made to interviewed households throughout the month of November, when most students have end-of-term exams.

Note that fewer households have reported average study times because not all households have students.

Also note that studying data comes mostly from primary school students: the households included in the estimation for general studying each have on average 2.75 primary school students and 0.43 secondary school students.

Table 13: Activities carried out using different lighting sources at endline

Activity – d.light households *(Number of users)*	*Tadooba* *(N=165)*	*Flash-light* *(N=190)*	*Paraffin lantern* *(N=69)*	*d.light D20g* *(N=482)*	*Non-D20g solar* *(N=36)*	*Electricity* *(N=18)*
General home lighting	68.5%	74.2%	87.0%	97.7%	94.4%	77.8%
Cooking	90.9%	59.5%	62.3%	79.3%	33.3%	33.3%
School work, reading	33.3%	27.4%	56.5%	79.5%	61.1%	55.6%
Walking around, going to the latrine	32.1%	86.3%	40.6%	77.0%	44.4%	55.6%
Preparing for bed	52.7%	53.2%	73.9%	88.8%	72.2%	77.8%
Shop lighting	6.1%	11.6%	8.7%	15.4%	22.2%	11.1%
Other income-generating work	10.9%	27.9%	18.8%	29.5%	19.4%	61.1%
Security lighting	2.4%	17.9%	5.8%	50.0%	58.3%	66.7%

Activity – Comparison households *(Number of users)*	*Tadooba* *(N=363)*	*Flash-light* *(N=296)*	*Paraffin lantern* *(N=155)*	- -	*Non-D20g solar* *(N=51)*	*Electricity* *(N=59)*
General home lighting	85.1%	87.2%	94.8%	-	98.0%	100.0%
Cooking	95.6%	64.9%	49.7%	-	45.1%	52.5%
School work, reading	57.0%	49.7%	69.0%	-	80.4%	79.7%
Walking around, going to the latrine	48.5%	86.8%	54.8%	-	47.1%	50.8%
Preparing for bed	74.4%	73.0%	83.9%	-	96.1%	91.5%
Shop lighting	2.5%	6.4%	5.8%	-	7.8%	20.3%
Other income-generating work	15.2%	28.7%	25.2%	-	23.5%	39.0%
Security lighting	5.2%	18.6%	10.3%	-	58.8%	78.0%

These data are for N=483 d.light households and N=488 comparison households. Households could report multiple sources, and multiple activities for each source. Many households noted in particular that flashlights and portable solar lanterns are good for moving around, whereas tadooba and more permanent high-quality lighting fixtures are not.

c) Energy expenditure outcomes

Table 14: Impact of owning a d.light D20g system on weekly household energy expenditure and income

Household energy outcome	*N of obs.*		*Baseline mean (95% CI)*	*Endline mean (95% CI)*	*Treatment effect (95% CI)*	*Treatment effect % (95% CI)*
Weekly lighting expenditure						
Expenditure on low-quality lighting sources	812	d.light	$0.84 ($0.74, $0.94)	$0.42 ($0.30, $0.54)	**-$0.58*** (-$0.86, -$0.30)	-58.0%* (-86.0%, -30.0%)
		Comp.	$0.82 ($0.68, $0.96)	$0.96 ($0.82, $1.10)		
Tadooba	874	d.light	$0.32 ($0.27, $0.37)	$0.13 ($0.10, $0.16)	**-$0.27*** (-$0.35, -$0.19)	-67.5%* (-87.5%, -47.5%)
		Comp.	$0.34 ($0.30, $0.38)	$0.42 ($0.37, $0.47)		
Flashlight	880	d.light	$0.26 ($0.22, $0.30)	$0.14 ($0.09, $0.19)	**-$0.14** (-$0.32, $0.04)	-50.0% (-114.3%, 14.3%)
		Comp.	$0.27 ($0.16, $0.38)	$0.28 ($0.18, $0.38)		
Paraffin lantern	926	d.light	$0.18 ($0.13, $0.23)	$0.04 ($0.02, $0.06)	**-$0.12*** (-$0.21, -$0.03)	-75.0%* (-131.3%, -18.8%)
		Comp.	$0.19 ($0.13, $0.25)	$0.15 ($0.11, $0.19)		
Other low-quality	930	d.light	$0.08 ($0.00, $0.16)	$0.05 (-$0.03, $0.13)	**-$0.05** (-$0.19, $0.09)	-50.0% (-190.0%, 90.0%)
		Comp.	$0.02 (-$0.00, $0.04)	$0.04 (-$0.00, $0.08)		
Expenditure on high-quality lighting sources (excluding cost of d.light D20g for d.light households at endline)	894	d.light	$0.19 ($0.08, $0.30)	$0.31 ($0.07, $0.55)	**-$0.21** (-$0.64, $0.22)	-40.4% (-123.1%, 42.3%)
		Comp.	$0.41 ($0.13, $0.69)	$0.58 ($0.34, $0.82)		
Total lighting expenditure (excluding cost of d.light D20g for d.light households at endline)	776	d.light	$1.03 ($0.88, $1.18)	$0.75 ($0.46, $1.04)	**-$0.77*** (-$1.28, -$0.26)	-50.7%* (-84.2%, -17.1%)
		Comp.	$1.18 ($0.90, $1.46)	$1.53 ($1.25, $1.81)		

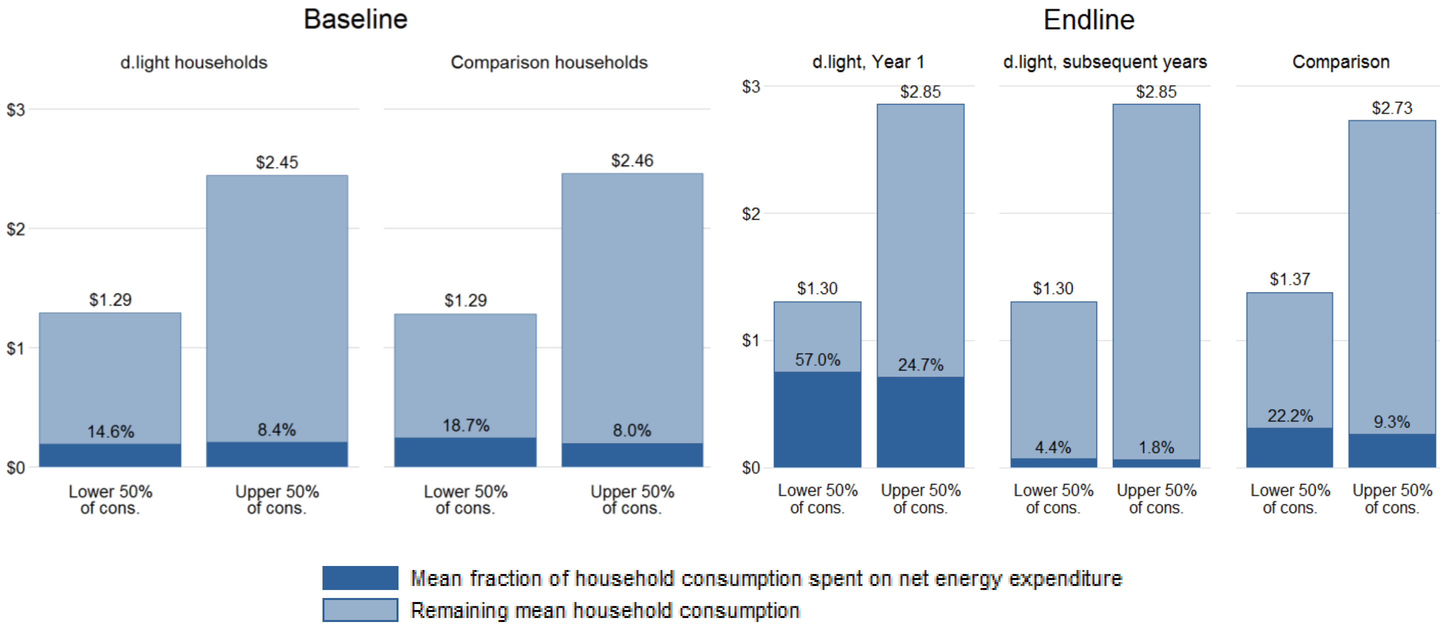
Weekly phone charging expenditure and income						
Phone charging expenditure	934	d.light	$0.37 ($0.33, $0.41)	$0.06 ($0.04, $0.08)	**-$0.31*** (-$0.37, -$0.25)	-83.8%* (-100.0%, -67.6%)
		Comp.	$0.33 ($0.30, $0.36)	$0.36 ($0.32, $0.40)		
Phone charging income	934	d.light	-	$0.29 ($0.22, $0.36)	**$0.16*** ($0.03, $0.29)	123.1%* (23.1%, 223.1%)
		Comp.	-	$0.13 ($0.04, $0.22)		
Net phone charging-related expenditure (expenditure – income)	934	d.light	$0.37 ($0.33, $0.41)	-$0.22 (-$0.29, -$0.15)	**-$0.47*** (-$0.62, -$0.32)	-188.0%* (-248.0%, -128.0%)
		Comp.	$0.33 ($0.30, $0.36)	$0.24 ($0.13, $0.35)		
Weekly number of and expenditure on trips made exclusively to purchase fuel for lighting or to charge phones						
Number of trips made exclusively to purchase fuel for lighting or to charge phones	932	d.light	-	0.74 (0.60, 0.88)	**-1.66*** (-1.94, -1.38)	-69.2%* (-80.8%, -57.5%)
		Comp.	-	2.55 (2.34, 2.76)		
Expenditure on trips made exclusively to purchase fuel for lighting or to charge phones	932	d.light	-	$0.01 ($0.00, $0.02)	**-$0.13*** (-$0.19, -$0.07)	-92.9%* (-135.7%, -50.0%)
		Comp.	-	$0.13 ($0.08, $0.18)		
Weekly net energy expenditure (lighting expenditure + phone charging expenditure – phone charging income + trip expenditure)						
Net energy expenditure in Year 1 of D20g ownership	776	d.light	$1.42 ($1.26, $1.58)	$4.93 ($4.62, $5.24)	**$2.99*** ($2.45, $3.53)	154.1%* (126.3%, 182.0%)
		Comp.	$1.52 ($1.24, $1.80)	$1.93 ($1.63, $2.23)		
Net energy expenditure in Year 2 of D20g ownership and subsequent years	776	d.light	$1.42 ($1.26, $1.58)	$0.53 ($0.22, $0.84)	**-$1.41*** (-$1.95, -$0.87)	-72.7%* (-100.5%, -44.8%)
		Comp.	$1.52 ($1.24, $1.80)	$1.93 ($1.63, $2.23)		

Total lighting expenditure refers to total household expenditure on all lighting sources used by the household. Because some households did not report data on expenditure on some lighting sources, but may have complete data on all low-quality (or all high-quality) lighting expenditure, the number of observations included in the analysis of total lighting expenditure is lower than it is for the low-quality and high-quality lighting expenditure analysis. Since different households are included in the estimates for low-quality, high-quality, and total lighting expenditure, the total lighting expenditure is slightly different from the sum of low-quality and high-quality lighting expenditure.

Tadooba and lantern expenditure were calculated based on the estimated amount of kerosene used per hour by each of these sources, and then multiplying through by the cost per unit of kerosene. Kerosene costs about 3000 UGX per liter ($1.20); most households buy either 250-300, 500, or 1000 mL at a time, roughly every week or so. (Shopkeepers will usually pour kerosene from a larger container they have into a reused soda or water bottle that the household uses to store kerosene). IDinsight tested various tadoobas and lanterns and measured that one hour of lantern usage goes through 25.6 mL of kerosene, which costs $0.031, and one hour of tadooba usage goes through 13.825 mL, which costs $0.017. These fuel usage levels were also compared to available literature and anecdotal experiences.

Note that net phone charging-related expenditure at baseline does not include phone-charging income because phone charging income data was only collected at endline. Net energy expenditure in Year 1 models the cost of the D20g over 1 year, based on a weekly cost of D20g of $4.40 ($230 divided by 52); in subsequent years the cost of the product is excluded.

Figure 1: Daily net energy expenditure at endline relative to estimated total household consumption (PAT)



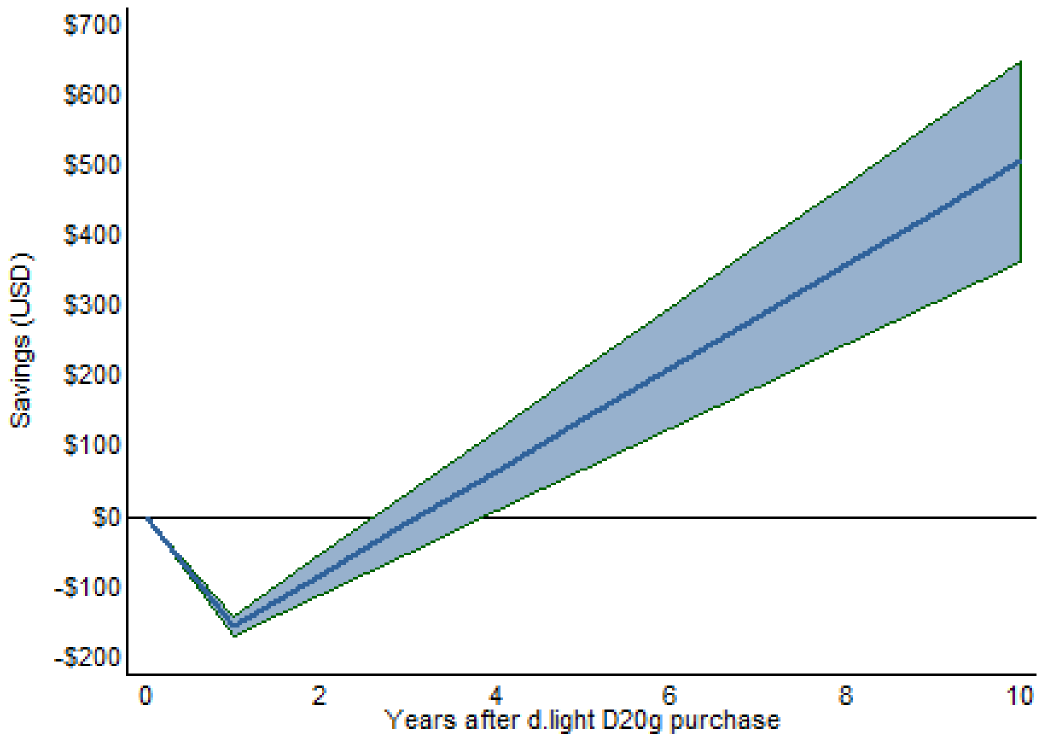
At baseline, these data are for N=191 and 174 d.light households in the lower and upper half of household consumption respectively, and N=174 and 191 comparison households. At endline, these data are for N=80 and 89 d.light households in the lower and upper half of household consumption respectively, and N=84 and 74 comparison households. Analysis was done after removing the top and bottom 10% of household consumption estimates, to avoid outliers for the estimate of fraction spent on net energy expenditure.

Daily net energy expenditure includes lighting expenditure, phone-charging expenditure minus phone charging income, and expenditure on trips to purchase fuel or charge phones. The daily net energy expenditure for d.light households includes the daily cost of the d.light D20g in Year 1 of ownership ($0.63), but not in subsequent years.

Daily consumption was estimated using the PAT. The PAT rather than the PPI was required for this estimate because the PPI cannot be traced back to numeric estimates of household consumption. Consumption refers to expenditure on goods and services that will be used directly by the household, which includes energy expenditures.

Households are divided into lower and upper halves according to whether their estimated total daily household consumption lies in the lower or upper half of estimated household consumption amongst all households in the sample; the cutoff at baseline is $1.59, and at endline is $1.98. The dollar amounts at the top of each bar gives the mean household consumption for the specified group, and the percentage above each dark blue portion gives the mean net energy expenditure as a percentage of mean household consumption.

Figure 2: Estimated net savings over time from owning a d.light D20g solar home system.



The estimates shown here take into account lighting expenditures, phone-charging expenditures, phone-charging income, and expenditure on trips to purchase fuel and charge phones. The shading depicts the 95% confidence interval of the estimate.

Savings are expressed relative to what d.light households would be paying had they not bought the d.light D20g. Estimates are calculated using the treatment effect on net energy expenditure in the first and in subsequent years, listed in Table 18 above: in Year 1, d.light households "lose savings" at a weekly rate given by the D20g treatment effect on net energy expenditure for Year 1, and in subsequent years, d.light households accumulate savings at a weekly rate of the treatment effect for subsequent years, eventually resulting in positive cumulative savings.

This estimate represents a best case scenario: it assumes that d.light households pay off their D20g over the course of Year 1 of ownership, that they and comparison customers continue their energy consumption behaviors as reported at endline, that the d.light D20g system continues operating at the same level, and that energy prices remain stable in eastern Uganda. **Note that this figure is likely a significant overestimate over longer time periods**, **as it is unlikely that all of these factors would hold constant over a ten-year time horizon.** Additional data collected over time on average useful life of the D20g system in field conditions on energy usage and energy expenditure would be required to make a more realistic projection of future cost savings from owning a D20g system.

d) Other socioeconomic outcomes

Table 15: Impact of owning a d.light D20g system on socioeconomic outcomes

Outcome variable	*N of obs.*		*Baseline mean (95% CI)*	*Endline mean (95% CI)*	*Treatment effect (95% CI)*	*Treatment effect % (95% CI)*
Self-reported wealth	934	d.light	3.93 (3.76, 4.10)	3.93 (3.76, 4.10)	**0.14** (-0.17, 0.45)	3.7% (-4.5%, 11.9%)
		Comp	3.66 (3.50, 3.82)	3.57 (3.40, 3.74)		
Self-reported social status	932	d.light	4.81 (4.61, 5.01)	4.77 (4.56, 4.98)	**0.21** (-0.17, 0.59)	4.6% (-3.7%, 12.9%)
		Comp	4.48 (4.29, 4.67)	4.29 (4.09, 4.49)		
Daily per capita consumption (2014 USD)[li]	166	d.light	$0.37 ($0.30, $0.44)	$0.53 ($0.41, $0.65)	**$0.02** (-$0.12, $0.16)	3.9% (-23.5%, 31.4%)
		Comp	$0.38 ($0.32, $0.44)	$0.46 ($0.38, $0.54)		

Self-reported wealth and social status are reported on a scale from 1 to 10, where 10 is highest.

In Uganda, wealth is interpreted as ownership of significant long-term assets, such as land, houses and buildings, and having money. Social status is interpreted as having the ability to provide for daily needs and live a high-quality life, such as having access to and being able to afford lighting, clean water, education for children, and healthcare.

Daily per capita consumption is calculated using the PAT. Because several questions for the PAT were not added until partway through the endline surveying process, the sample size for this data point is smaller.

Table 16: Impact of owning a d.light D20g system on household assets

Asset	*N of obs.*		*Baseline mean (95% CI)*	*Endline mean (95% CI)*	*Treatment effect (95% CI)*	*Treatment effect % (95% CI)*
Local cattle	924	d.light	1.45 (1.15, 1.75)	1.20 (0.98, 1.42)	**0.16** (-0.24, 0.56)	15.4% (-23.1%, 53.8%)
		Comp.	1.03 (0.79, 1.27)	0.76 (0.62, 0.90)		
Exotic cattle	920	d.light	0.33 (0.24, 0.42)	0.35 (0.25, 0.45)	**0.07** (-0.08, 0.22)	25.0% (-28.6%, 78.6%)
		Comp.	0.38 (0.24, 0.52)	0.37 (0.21, 0.53)		
Horses, mules, and donkeys	922	d.light	0.01 (-0.01, 0.03)	0.00 (-0.01, 0.01)	**-0.02** (-0.06, 0.02)	-100.0% (-300.0%, 100.0%)
		Comp.	0.00 (0.00, 0.00)	0.02 (-0.01, 0.05)		
Goats	922	d.light	2.78 (1.07, 4.49)	1.99 (1.55, 2.43)	**0.01** (-2.06, 2.08)	0.5% (-104.0%, 105.1%)
		Comp.	1.20 (0.72, 1.68)	1.20 (1.03, 1.37)		
Sheep	920	d.light	0.18 (0.05, 0.31)	0.09 (0.04, 0.14)	**-0.01** (-0.16, 0.14)	-10.0% (-160.0%, 140.0%)
		Comp.	0.07 (0.03, 0.11)	0.03 (0.01, 0.05)		
Pigs	926	d.light	0.51 (0.36, 0.66)	0.65 (0.43, 0.87)	**0.22** (-0.12, 0.56)	51.2% (-27.9%, 130.2%)
		Comp.	0.68 (0.38, 0.98)	0.63 (0.29, 0.97)		
Chickens	926	d.light	13.84 (7.05, 20.63)	13.33 (9.46, 17.20)	**-0.13** (-8.61, 8.35)	-1.0% (-64.0%, 62.0%)
		Comp.	9.20 (6.51, 11.89)	8.09 (5.96, 10.22)		
Ducks	920	d.light	0.50 (0.33, 0.67)	0.66 (0.42, 0.90)	**0.14** (-0.09, 0.37)	26.9% (-17.3%, 71.2%)
		Comp.	0.29 (0.18, 0.40)	0.31 (0.18, 0.44)		
Cooking pots and pans	926	d.light	6.45 (6.15, 6.75)	6.06 (5.77, 6.35)	**-0.01** (-0.51, 0.49)	-0.2% (-8.4%, 8.1%)
		Comp.	6.03 (5.76, 6.30)	5.54 (5.28, 5.80)		
Panga (machetes)	894	d.light	1.24 (1.15, 1.33)	1.20 (1.12, 1.28)	**-0.10** (-0.24, 0.04)	-7.7% (-18.5%, 3.1%)
		Comp.	1.14 (1.07, 1.21)	1.14 (1.05, 1.23)		
Hoes	892	d.light	4.99 (4.61, 5.37)	4.60 (4.29, 4.91)	**-0.16** (-0.58, 0.26)	-3.4% (-12.2%, 5.5%)
		Comp.	4.15 (3.90, 4.40)	4.06 (3.82, 4.30)		

e) Health & personal safety outcomes

Table 17: Impact of owning a d.light D20g system on health outcomes

Outcome variable	*N of obs.*		*Baseline mean (95% CI)*	*Endline mean (95% CI)*	*Treatment effect (95% CI)*	*Treatment effect % (95% CI)*
Has had household member burned by lighting source	932	d.light	6.44% (4.21%, 8.67%)	0.86% (0.02%, 1.70%)	**-6.39 pp*** (-10.41 pp, -2.37 pp)	-88.1%* (-143.6%, -32.7%)
		Comp.	4.94% (2.97%, 6.91%)	6.01% (3.85%, 8.17%)		
Has had fire caused by lighting source	934	d.light	7.92% (5.47%, 10.37%)	0.43% (-0.16%, 1.02%)	**-5.96 pp*** (-10.18 pp, -1.74 pp)	-93.3%* (-159.3%, -27.2%)
		Comp.	6.21% (4.02%, 8.40%)	6.00% (3.84%, 8.16%)		
Has had household member with cough in past month	932	d.light	66.95% (62.67%, 71.23%)	61.37% (56.94%, 65.80%)	**-8.53 pp** (-17.12 pp, 0.07 pp)	-12.2% (-24.5%, 0.1%)
		Comp.	68.67% (64.45%, 72.89%)	69.96% (65.79%, 74.13%)		
Self-reported per-sonal health	908	d.light	5.28 (5.07, 5.49)	5.31 (5.09, 5.53)	**0.08** (-0.32, 0.48)	1.5% (-6.1%, 9.2%)
		Comp.	4.89 (4.67, 5.11)	4.80 (4.58, 5.02)		

Burns and fires were self-reported for the last six months at baseline and last three months at endline. Burns, fires, and coughs are re-ported as the percentage of households who have had at least one household member or one instance of experiencing the specified out-come.
Treatment effect for these outcomes is expressed in percentage points (pp), while the treatment effect percent shows the percent change from baseline values. Self-reported personal health is reported on a scale from 1 to 10, where 10 is highest.

III. D20g customer use & satisfaction

Table 18: Main reasons for purchasing solar product or connecting to electricity

Main reason (*N of households*)	*D20g* (*N=483*)	*Non-D20g solar*[lii] (*N=85*)	*Electricity* (*N=77*)
General home lighting	45.1%	52.9%	49.4%
Economic reasons (will be cheaper over time)	43.9%	36.5%	20.8%
Health and safety reasons (fumes, fire)	36.9%	31.8%	19.5%
Phone charging	34.0%	21.2%	23.4%

Note that the non-D20g solar category includes systems and portable lanterns in this table.
Several respondents who listed economic reasons for purchasing the d.light D20g system specifically noted the ability to pay in installments.
Other reasons for using electricity include finding their house already connected (e.g. if renting).
Other reasons for purchasing d.light and non-d.light solar products include having a more stable alternative to electricity and replacing a previous solar product.
Other reasons for purchasing a d.light solar system include being told or inspired by friends to buy a solar product.

Table 19: Satisfaction with the d.light D20g system

	N of obs.	*Mean (95% CI)*	*Median*	*Std Dev*	*Min*	*Max*
Overall satisfaction	481	6.97 (6.75, 7.19)	7.00	2.47	1.00	10.00

Satisfaction is self-reported on a scale from 1 to 10.

Figure 3: Respondent's self-reported change in overall happiness and satisfaction with their home due to owning the d.light D20g system

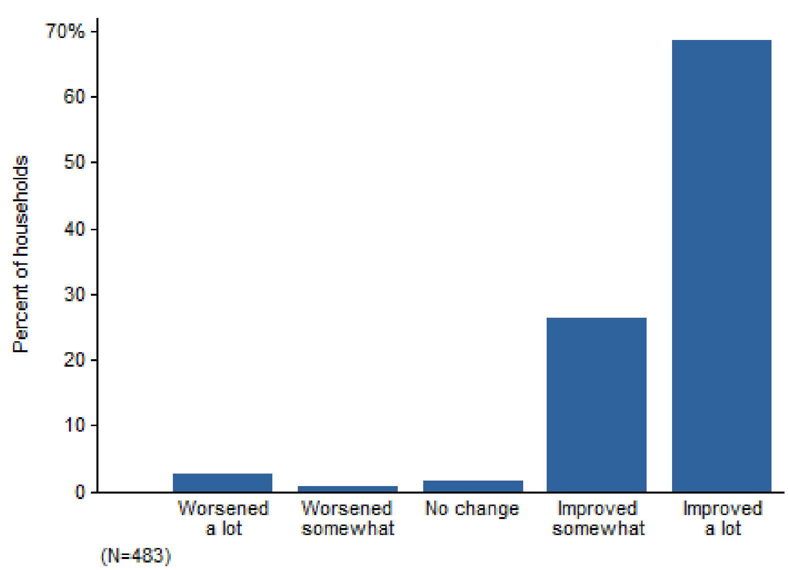


Table 20: How has owning the d.light D20g solar home system changed your overall happiness and satisfaction with your home?

Reason	*% of households*
Better quality light	26.5%
More hours of lighting	24.0%
Don't need to buy lighting fuel	19.2%
Other positive response	45.8%
Negative response	2.1%

These data are for N=475 d.light households. Only respondents who reported a change in overall happiness and satisfaction with their home due to the d.light D20g system were asked a follow-up question about how it changed. All responses (except for "Negative response") are positive responses about how the d.light D20g have improved the respondent's happiness and satisfaction with their home. Negative responses are complaints about payments, disconnections, and lights not working.

Table 21: d.light households' communication to others about d.light D20g

Has respondent told friends and family:	*Yes*	*No*
That they have the d.light D20g solar home system	97.9%	2.1%
To buy the d.light D20g solar home system	96.9%	3.1%

These data are for N=482 households.

Appendix C: Technical Note - Matching methodology and results

The matching strategy described below was reviewed by one of IDinsight's external Technical Advisors, in addition to the technical staff of IDinsight. Please contact d.light or IDinsight for a full technical annex or for further details on the matching used for this study.

IDinsight used the Genetic Matching algorithm for matching, which has a good track record of producing matched samples with low bias.[liii,liv,lv,lvi]

Variable Selection

The Genetic Matching algorithm finds weights for covariates of interest, specified a priori, to optimally balance treatment and comparison groups across these covariates. While there are different opinions on which variables should be included in matching,[lvii] the primary requirements are that the covariates should influence treatment status and also influence the outcome of interest.[lviii] For the purposes of this evaluation, we used the following variables to balance in the Genetic Matching algorithm:

- **Baseline Outcomes:** Matching on baseline outcomes for the measures of interest helps to ensure unconfoundedness and balance on outcomes before the treatment. In particular, we included energy expenditure, time spent on productive activities, and time spent studying. Note that we did *not* include self-reported measures of health, wealth, or social standing, as the baseline outcomes were collected *after* the d.light customers had purchased their system and purchasing the system may have already had an impact on these households' self-perceived standing.
- **Progress out of Poverty (PPI) Scores:** The baseline survey incorporated the Progress out of Poverty assessment tool for Uganda.[lix] The PPI score for each household in the treatment and comparison groups was computed prior to the purchase of a d.light D20g system, and included as a covariate for the Genetic Matching algorithm to balance across treatment and control. The logic behind this is simple. Poorer households will be less likely to be able to afford the d.light home solar system, may be less educated, and spend less per day on energy. As a result, "poverty," as measured by the PPI, influences both treatment selection and outcome measures.
- **Prior Lighting Sources:** A household's previous experience with different energy sources likely has a bearing on whether it purchases a d.light D20g system, how much the household spends on fuel, and the quantity and quality of lighting available for the household. The lighting sources were included as a binary indicator for non-D20g solar product usage, and as a propensity score constructed from remaining lighting sources. Note that only lighting sources used by more than 2% of the treatment group were used.
- **Distance from Urban Center:** There is a correlation between electricity availability and a household's "remoteness," as households farther from urban centers are more costly to electrify. Moreover, electricity partially obviates the need for a solar lantern, making a household with electricity less likely to purchase a d.light solar home system. Distances are calculated using GPS coordinates of the households collected during the baseline survey, and GPS coordinates of major urban centers (Jinja, Iganga, Kamuli, and Busia).
- **Number of Phones Per Capita:** One measure that influences both energy expenditure and may influence purchase of the d.light unit is number of cellular phones the household owns. In particular, the more phones a household owns, the higher its expenditure on phone charging. A household with more phones may be more likely to purchase a d.light unit in order to charge the phones.
- **Household Head Characteristics:** The characteristics of the household head differ across between treatment and comparison groups.
    - **Occupation:** It may well be the case that the household head's occupation affects both treatment assignment and our outcomes of interest. For example, a teacher is more likely to have the

means to buy a d.light D20g system than is a subsistence farmer. Binary variables for farmer, professional, self-employed, and other employment are used as covariates.

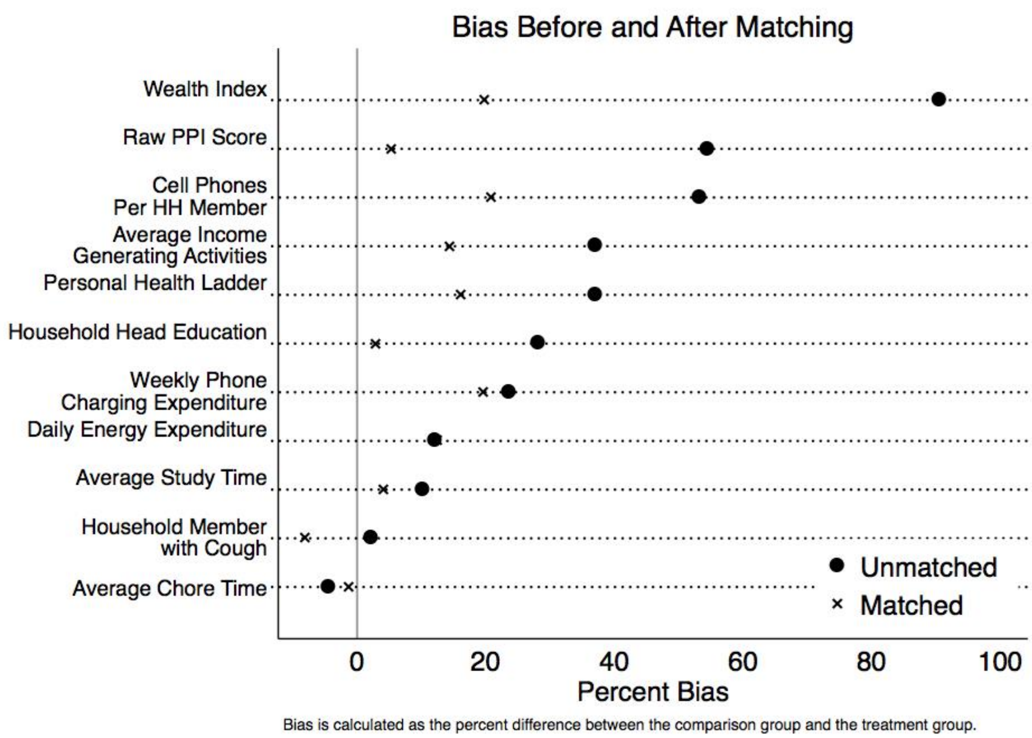
- **Years of education:** Similarly, more educated heads of household will likely have higher incomes and have different outcomes (particularly for studying) than lower-income heads of households. As d.light households tend to have higher-educated heads of households, education may affect both treatment assignment and outcomes of interest.

Matching Results

After 500 comparison households have been selected for the matching group, IDinsight tested the matching results to ensure that treatment and control groups are balanced.[lx]

The matched results show a substantial decrease in average bias between the full sample (mean bias of 23%) versus the matched sample (mean bias of 8.6%). Figure 4 below shows the change in bias for selected variables before and after matching.

Figure 4: Bias comparison before and after matching



Tables 22 and 23 show the detailed outcomes of the matching algorithm. In general, most variables included in the matching algorithm saw substantial reductions in bias. Most variables also substantially increased balance, as measured by the Kolmogorov-Smirnov test. While some variables remain statistically significantly different between treatment and comparison groups, we would expect some variables to be statistically significantly different, even in a randomized study. As such, IDinsight feels that the matches achieve good balance on outcomes of interest and indicators likely to affect both outcomes of interest and purchase of the d.light D20g system.

Table 22: High-Level Matching Results and Tests for Joint Significance

Sample	*Psuedo-R^2*	*Likelihood Ratio*	*Likelihood Ratio p-Value*	*Mean Bias*	*Median Bias*
Full Sample	0.19	425.84	<0.0001	23.4	22.1
Matched Sample	0.01	16.83	0.265	6.7	7.0

Psuedo-R^2 is a watch of measuring the explanatory power when the outcome of interest is a binary variable. In this case, treatment status is regressed on the variables used in the matching. Before matching, we should expect to explain a significant fraction of the variance in treatment status. After matching, however, we should expect the psuedo-R^2 to be closer to zero.
The likelihood ratio is a way to determine whether a set of variables jointly explains an outcome.
Mean and median bias refer to the mean and median bias of all variables used to match on.

Table 23: Variable-Level Matching Results

Indicator	*Sample*	*d.light Households*	*Comparison Households*	*Percent Bias*	*Percent reduction in bias*	*t-Test*	*t-Test p-value*	*KS Test*	*KS Test p-value*
Household Member Had a Cough in Past 30 Days (Binary)	Full Sample	66%	65%	2%	-50%	0.43	0.67		
	Matched Sample		68%	-3%		-0.54	0.59		
Personal Health Ladder*	Full Sample	5.3	4.5	37%	47%	7.12	0.00	0.17	0.00
	Matched Sample		4.9	19%		3.08	0.00	0.16	0.08
Average Income-Generating Activities (in Hours)	Full Sample	2.5	1.7	37%	69%	7.91	0.00	0.16	0.00
	Matched Sample		2.3	12%		1.71	0.09	0.06	0.38
Average Chore Time (in Hours)	Full Sample	2.5	2.6	-5%	-106%	-0.86	0.39	0.04	0.61
	Matched Sample		2.7	-9%		-1.51	0.13	0.07	0.10
Average Study Time (in Hours)	Full Sample	0.62	0.53	10%	55%	2.05	0.04	0.05	0.31
	Matched Sample		0.58	5%		0.70	0.48	0.03	0.99
Weekly Phone Charging Expenditure (in USD)	Full Sample	0.38	0.29	24%	52%	4.85	0.00	0.12	0.00
	Matched Sample		0.34	11%		1.72	0.09	0.06	0.27
Daily Energy Expenditure (in USD)	Full Sample	0.13	0.11	12%	23%	2.48	0.01	0.07	0.05
	Matched Sample		0.11	9%		1.28	0.20	0.07	0.18
Household Head Education (in Years)*	Full Sample	7.5	6.4	28%	100%	5.44	0.00	0.10	0.00
	Matched Sample		7.5	0%		0.02	0.98	0.03	0.97
PPI Score (out of 100)	Full Sample	60	54	55%	94%	10.31	0.00	0.22	0.00
	Matched Sample		59	3%		0.59	0.56	0.03	0.97
Distance to nearest urban center (in km)	Full Sample	39.7	38.6	5%	-116%	0.89	0.38	0.05	0.27
	Matched Sample		37.3	10%		1.60	0.11	0.07	0.15
Cell Phones Per Household Member	Full Sample	0.40	0.26	53%	79%	11.25	0.00	0.24	0.00
	Matched Sample		0.37	11%		1.71	0.09	0.05	0.43
Asset Propensity Score*	Full Sample	0.35	0.22	91%	40%	18.35	0.00	0.35	0.00
	Matched Sample		0.27	51%		8.37	0.00	0.22	0.00
Lighting Propensity Score	Full Sample	0.28	0.24	42%	76%	8.53	0.00	0.19	0.00
	Matched Sample		0.28	10%		1.51	0.13	0.04	0.80

Solar Lights (Binary)	Full Sample	13.0%	6.3%	23%	88%	4.75	0.00	
	Matched Sample		12.1%	3%		0.38	0.70	
Household Head Occupation								
Farm Worker (Binary)	Full Sample	35.5%	57.1%	-44%	84%	-8.15	0.00	
	Matched Sample		38.9%	-7%		-1.11	0.27	
Professional (Binary)	Full Sample	12.4%	7.6%	16%	87%	3.25	0.00	
	Matched Sample		11.8%	2%		0.29	0.77	
Self-Employed (Binary)	Full Sample	47.5%	28.7%	40%	83%	7.85	0.00	
	Matched Sample		44.3%	7%		1.01	0.31	
Others (Binary)	Full Sample	4.6%	6.6%	-9%	100%	-1.63	0.10	
	Matched Sample		4.6%	0%		0.00	1.00	

KS test refers to the Kolmogorov-Smirnov test for equality of distributions, which attempts to determine whether two samples were drawn from the same distributions.
Percent reduction in bias refers to the change in bias divided by the original bias. Note that a negative change in bias means that bias has actually increased in the matched sample.
Variables with the "Binary" indicator are variables that are coded as 1 if a household has that characteristic and 0 if a household does not have that characteristic. Note that the Kolmogorov-Smirnov test is not applicable to binary variables.
Asterisks denote variables not included in the genetic matching algorithm.

Appendix D: Technical Note - Analysis methodology

Regression equations and estimation

For difference-in-difference analysis, we regress for each i^{th} household

$$\Delta Y_i = \delta + \alpha D i \quad + X_i' \beta + \varepsilon_i$$

where $\Delta Y_i \equiv Y_{i,\text{endline}} - Y_{i,\text{baseline}}$ is the change in the household's outcome from baseline to endline, D_i is a treatment indicator, X_i is a vector of covariates, and β is a vector of coefficients for the covariates.

From this regression, we obtain α, our DID treatment effect estimator. δ gives the intercept for change in outcome over time not attributable to treatment or covariates, and β gives the average effect of unit increases in covariates on any change in outcome over time not attributable to treatment.

There are several outcomes for which there is only endline data and no baseline data because the relevant survey question was either added to or significantly modified in the endline survey. For these outcomes, analysis is done using a simple differences comparison between d.light and comparison households' endline data, rather than difference-in-differences. We regress for each i^{th} household

$$Y_i = \delta + \alpha D_i + X_i' \beta + \varepsilon_i$$

where the regressed variable Y_i is now the household's outcome at endline. α is the simple differences treatment effect estimator, and δ is the intercept for the endline outcome not attributable to treatment or covariates.

For outcomes that are averaged across individuals at the household level (hours of chores, income-generating activities, and studying), standard errors of the treatment effect estimator are calculated adjusting for the fact that the variance of the outcome may vary from household to household. Households with more individuals, and hence more data points for hours spent doing activities to average, will have a smaller variance than households with fewer individuals.

Covariates

The same covariates are used in all regression analyses, for internal consistency. Values for all covariates used will be taken from the baseline survey, to avoid any problems with endogeneity arising from correlation of treatment with changes in covariates from baseline to endline. To select covariates, all variables used in matching that are not baseline values of outcomes are used. Several non-outcome variables that were not included in the matching have been added as well.

- **Baseline Progress out of Poverty (PPI) Scores:** The baseline survey incorporated the Progress out of Poverty assessment tool for Uganda.lxi Poorer households will be less likely to be able to afford the d.light home solar system, may be less educated, and spend less per day on energy. As a result, "poverty," as measured by the PPI, influences both treatment selection and outcome measures.
- **Prior Lighting Sources:** A household's previous experience with different energy sources likely has a bearing on whether it purchases a d.light D20g system, how much the household spends on fuel, and the quantity and quality of lighting available for the household. The lighting sources will be included as a binary indicator for non-D20g solar product usage, and as a propensity score constructed from remaining

lighting sources. Note that only lighting sources used by more than 2% of the treatment group will be used.

- **Baseline Distance from Urban Center:** There is a correlation between electricity availability and a household's "remoteness," as households farther from urban centers are more costly to electrify. Moreover, electricity partially obviates the need for a solar lantern, making a household with electricity less likely to purchase a d.light solar home system. Distances are calculated using GPS coordinates of the households collected during the baseline survey, and GPS coordinates of major urban centers (Jinja, Iganga, Kamuli, and Busia).
- **Baseline Number of Phones Per Capita:** One measure that influences both energy expenditure and may influence purchase of the d.light unit is number of cellular phones the household owns. In particular, the more phones a household owns, the higher its expenditure on phone charging. A household with more phones may be more likely to purchase a d.light unit in order to charge the phones.
- **Baseline Household Head Characteristics:** The characteristics of the household head differ across between treatment and comparison groups.
    - **Occupation:** It may well be the case that the household head's occupation affects both treatment assignment and our outcomes of interest. For example, a teacher is more likely to have the means to buy a d.light D20g system than is a subsistence farmer. Binary variables for farmer, professional, self-employed, and other employment are used as covariates.
    - **Years of education:** Similarly, more educated heads of household will likely have higher incomes and have different outcomes (particularly for studying) than lower-income heads of households. As d.light households tend to have higher-educated heads of households, education may affect both treatment assignment and outcomes of interest.
- **Baseline mobile money usage:** Usage of mobile money may be an indicator of a household's openness to adopting new technologies.

Appendix E: Technical Note – p-values for outcomes determined through differences-in-differences

A statistical test produces what is called a *p*-value, which is the probability as determined by the test that one group is different from another (here, the d.light households and the comparison households). The *p*-value is then used to determine whether the difference is statistically significant. Statistical significance is determined by specifying a pre-determined cutoff for the probability, and then determining whether the *p*-value is above or below that cutoff point. Common significance levels are 1%, 5%, and 10%. In this document we report statistically significant treatment effects as those with a significance level below 5% (p-value < 0.05), and mark them with an asterisk (*).

Table 24: Treatment effects and p-values for key outcomes

Outcome	*Treatment effect (95% CI)*	*Treatment effect % (95% CI)*	*p-value*
Low-quality lighting source hours used daily	**-4.29*** (-5.72, -2.86)	-62.6%* (-83.5%, -41.8%)	0.000
High-quality lighting source hours used daily	**6.24*** (4.62, 7.86)	156.8%* (116.1%, 197.5%)	0.000
Total lighting hours used daily	**2.94*** (0.51, 5.37)	29.0%* (5.0%, 52.9%)	0.018
Hours spent on chores daily, averaged over house-hold members aged > 3 years	**-0.07** (-0.38, 0.24)	-2.4% (-12.9%, 8.2%)	0.649
Hours spent on income-generating activities daily, averaged over household members aged > 10 years	**-0.24** (-0.69, 0.21)	-6.4% (-18.4%, 5.6%)	0.116
Hours spent studying daily, averaged over household students	**0.04** (-0.15, 0.23)	5.1% (-19.0%, 29.1%)	0.673
Weekly lighting expenditure, not including d.light cost	**-$0.77*** (-$1.28, -$0.26)	-50.7%* (-84.2%, -17.1%)	0.003
Weekly phone charging expenditure	**-$0.31*** (-$0.37, -$0.25)	-83.8%* (-100.0%, -67.6%)	0.000
Weekly income from phone charging	**$0.16*** ($0.03, $0.29)	123.1%* (23.1%, 223.1%)	0.023
Weekly expenditure on trips to purchase fuel or charge phones	**-$0.13*** (-$0.19, -$0.07)	-92.9%* (-135.7%, -50.0%)	0.000
Net weekly energy expenditure in Year 1 of D20g ownership (lighting + phone charging + trips)	**$2.99*** ($2.45, $3.53)	154.1%* (126.3%, 182.0%)	0.000
Net weekly energy expenditure in Years 2-10 of D20g ownership (lighting + phone charging + trips)	**-$1.41*** (-$1.95, -$0.87)	-72.7%* (-100.5%, -44.8%)	0.000
Self-reported wealth (1-10 scale)	**0.14** (-0.17, 0.45)	3.7% (-4.5%, 11.9%)	0.393
Self-reported social status (1-10 scale)	**0.21** (-0.17, 0.59)	4.6% (-3.7%, 12.9%)	0.282
Has had household member burned by lighting source (percentage points)	**-6.39 pp*** (-10.41%, -2.37%)	-88.1%* (-143.6%, -32.7%)	0.002
Has had fire caused by lighting source (percentage points)	**-5.96 pp*** (-10.18%, -1.74%)	-93.3%* (-159.3%, -27.2%)	0.006
Has had household member with cough in past month (percentage points)	**-8.53 pp** (-17.12%, 0.07%)	-12.2% (-24.5%, 0.1%)	0.052
Self-reported personal health (1-10 scale)	**0.08** (-0.32, 0.48)	1.5% (-6.1%, 9.2%)	0.715

[i] Matching is a technique that forms a statistically valid comparison group by pairing individuals that did not receive the treatment to individuals in the treatment group on the basis of observable characteristics. When done correctly, matching accounts for all possible sources of bias due to observable characteristics. A matching methodology was chosen (instead of a randomized controlled trial) because it was the most rigorous methodology that would not interfere with d.light's standard operations with respect to the D20g system.

[ii] Difference-in-differences is a technique that estimates the impact of a program by comparing change over time in the treatment group—in this case D20g customers—relative to the change of a comparison group—here, non-customers. There are two survey rounds, baseline and endline, to capture the change over time. Difference-in-differences helps eliminate bias due to unobservable factors that may change over time for all respondents that are not due to treatment.

[iii] This method can measure the causal effect if a key untestable assumption holds: it assumes that in the absence of the treatment, the treatment and comparison groups would have evolved in the same manner, such that the comparison group is an accurate estimate of what the treatment group would have looked like.

[iv] In the body of this report, evaluation results are marked as statistically significant if they are significant at the 95% level. *p*-values quantifying the level of statistical significance for key outcomes are included in Appendix C. Note that the percent change listed in parenthesis after each result is the percent change in the quantity of the particular item measured. Savings that accrue from phone charging, for example, relate to the savings only in that category and not to overall savings or expenditure.

[v] Flashlights refer to any battery-powered light, including large LED lights.

[vi] Minimum product lifetime estimate obtained from d.light product team in laboratory conditions; field conditions may vary

[vii] The decrease in coughs is not significant at the 95% significance level, but it is extremely close to being significant.

[viii] International Energy Agency: World Energy Outlook 2014 Electricity Database

[ix] Energy Poverty: How to Make Modern Energy Access Universal? (International Energy Agency, United Nations Development Programme, United Nations Industrial Development Organization, 2010): 17.

[x] A 2012 study on the impact of solar energy in Rwanda published in September 2014 is one of a few rigorous studies of this topic. For the paper, see https://editorialexpress.com/cgi-bin/conference/download.cgi?db_name=CSAE2015&paper_id=854.

[xi] Grimm, M., et al. October 2014. "A first step up the energy ladder? Low cost solar kits and household's welfare in rural Rwanda." IZA Discussion Paper (8594).

[xii] Furukawa, Chishio. "Do Solar Lamps Help Children Study? Contrary Evidence from a Pilot Study in Uganda." *Journal of Development Studies* 50.2 (2014): 319-341.

[xiii] Samad, Hussain A., et al. "The benefits of solar home systems: an analysis from Bangladesh." *World Bank Policy Research Working Paper* 6724 (2013).

[xiv] Furukawa, Chishio. "Health and safety benefits of replacing kerosene candles by solar lamps: Evidence from Uganda." Working Paper, 2012.

[xv] Hanna, R., Duflo, E., & Greenstone, M. (2012) Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves. *NBER Working Paper Series.*

[xvi] A matching methodology with difference-in-differences analysis was chosen instead of a randomized controlled trial (RCT) because of operational considerations. Among other logistical changes, a randomized controlled trial would have required d.light to give away D20g systems, rather than allowing households to purchase them, even though the financial decisions of buying and paying for a D20g system over time could greatly influence the impact of the D20g system. Matching was chosen, therefore, as the most rigorous methodology consistent with d.light's existing operations.

[xvii] d.light customers were surveyed from 16 districts in southeastern Uganda: Bugiri, Buikwe, Busia, Butaleja, Buyende, Iganga, Jinja, Kaliro, Kamuli, Kayunga, Luuka, Mayuge, Mukono, Namayingo, Namutumba, and Pallisa.

[xviii] Initially, comparison households were selected at random out of the entire village population. A preliminary comparison between households with d.light D20g systems and those without showed similarities on most key variables except for roof type and cell phone ownership. As a result, inclusion criteria for the remaining 70% of the

comparison households were revised to require owning a cell phone and having a metal roof. This revision was made so that comparison households more closely resembled d.light households in terms of household income levels.

[xix] Please see Appendix C for some technical details on matching; contact d.light or IDinsight for a full technical annex on the matching methodology or for further details.

[xx] Comparing the d.light households' and comparison households' change between baseline and endline, rather than just comparing endline results, controls for the impact of other factors besides D20g ownership over the same time period on particular outcomes. See Appendix A's section on "estimation of impact" for further information.

[xxi] Endline respondents were divided into three groups, according to the date during which they were first surveyed in the baseline. In an effort to minimize the burden on participants, the survey was as streamlined as possible: endline survey interviews averaged 61 minutes per d.light household and 46 minutes for comparison households. This difference is due to a number of questions that were asked only to households that own the d.light system.

[xxii] The endline sample size is less than 1,000 total for a number of reasons. Six comparison households bought the d.light D20g system after the baseline survey and so were removed from the comparison group at endline, because they had effectively become treatment households (which contaminates difference in differences analysis). A different six households were removed from the treatment group because they were actually comparison households that were mistakenly identified as d.light households during the baseline survey. One household refused to answer the endline survey and eighteen were unable to be interviewed due to a change in household circumstance (i.e. the heads of household or the entire household were unable to be located).

[xxiii] 85% of respondents were in a geographic delineation of at least 10,000 people living in the area.

[xxiv] The international $2.50/day/per capita poverty line was used for this measure. This percentage was determined by the Progress out of Poverty Indicator, a tool developed by the Grameen Foundation to estimate a household's likeliness of living under particular poverty lines, as a substitute for lengthy but still often inaccurate income surveys in the developing world, where household income is very hard to document. The questionnaire consists of ten questions on asset ownership and other household characteristics, and is quick to administer and score. More information on the PPI is available at www.progressoutofpoverty.org.

[xxv] These figures were determined by USAID's Poverty Assessment Tool. The PAT is conceptually very similar to the PPI, but only the PAT can be backed-out into numeric estimates of household consumption. More information on the PAT is available at www.povertytools.org.

[xxvi] (2010) Uganda National Household Survey 2009/10, Socio-Economic Module, Abridged Report, Kampala, http://www.ubos.org/UNHS0910/unhs200910.pdf.

[xxvii] 55% of the bottom third and 48% of the middle third used tadoobas as their primary lighting source. This percentage is 25% for the top third, compared to the slightly higher incidence (28%) of households using flashlights as their primary source.

[xxviii] Note that these definitions differ from those used by the Grameen Foundation's Progress out of Poverty Indicator (PPI) and USAID's Poverty Assessment Tool (PAT), which characterize kerosene lanterns as high quality.

[xxix] At baseline, primary lighting source is determined by which source each household reported using for the greatest number of hours. At endline, primary lighting source was directly self-reported by respondents.

[xxx] Accounts for tadooba and paraffin lantern usage.

[xxxi] Note that all of these values represent minimum percentages, since about 10% of respondents did not report data on this topic.

[xxxii] -44% for flashlights, -56% for paraffin lanterns, and -56% for tadoobas.

[xxxiii] Note that adding the change in high quality and low quality light does not yield the total change in lighting hours. This is because a different subsample was used for each of the three calculations. Households that had missing data in these parts of the survey and their matched counterparts were not included in the particular calculations which compared this data.

[xxxiv] Grimm et al., in a study of a lower-capacity solar product in Rwanda (see endnote xi for citation), similarly find an increase in total hours of lighting and no impact on total hours spent on chores and studying. They do note that people with the solar system tended to use it for such activities when they used another source or no source before, and that children shifted studying hours from the afternoon to after nightfall.

[xxxv] All household expenditures and income are expressed in current (2014) US dollars. Amounts reported in Ugandan shillings are converted at a rate of 2500 UGX = $1 USD. While this was not the exchange rate during the endline survey (2660.00 UGX = $1 USD on October 27, 2014, the last day of endline surveying), this rate was used for the baseline report, and is closer to the exchange rate during the baseline survey (2457.75 UGX = $1 USD on January 22, 2014, the first day of baseline surveying). Despite currency fluctuations, Ugandan consumers did not experience high inflation during the length of this study and thus paid constant prices in Ugandan Shillings. Converting into US dollars using a fixed exchange rate ensures that the currency fluctuations do not distort the reporting of results, as the exchange rate did not likely have a major influence in the consumer decisions of rural Ugandans.

[xxxvi] Note that the statistical average net energy expenditure at baseline for d.light households, $1.42, is slightly different than $1.03 + $0.37 = $1.40. This is because some households reported phone charging expenditures but not lighting expenditures (or vice versa). As such, the estimates of phone charging expenditures and lighting expenditures separately are generated using different households than the estimate of the net energy expenditure, which uses only data from households that reported both phone charging and lighting expenditures.

[xxxvii] Based on consumption estimates generated by the PAT.

[xxxviii] Despite the fact that this population relies predominantly on tadoobas, which consume relatively low volumes of kerosene (and produce similarly low light output), this level of baseline expenditure (absolute and relative) is in fact higher than other market research efforts indicate, for example: a study conducted by the International Finance Corporation's Lighting Africa initiative found that weekly spending on tadooba-style implements ranged from $0.15/week in Tanzania to $0.48/week in Ghana and on paraffin lantern-style implements from $.50/week in Zambia to $2.23/week in Kenya (International Finance Corporation. "The Off-Grid Lighting Market in sub-Saharan Africa." 2011.); a randomized control trial around solar lanterns in Uganda found $0.56/week (200 UGX/day) (Chishio Furukawa. "Health and Safety Benefits of Replacing Kerosene Candles by Solar Lamps: Evidence from Uganda." Brown University, 2012.); and market research conducted by the World Bank found a national average of 6% spending on non-modern lighting fuels like kerosene and biomass (World Bank. "Expenditure of Low-Income Households on Energy." 2010. The study places percentage of spending on non-modern fuel for lighting like kerosene at 4% for urban Uganda households and 7% for rural households).

[xxxix] Most customers are expected to pay off the D20g in one year; however, repayment rates vary, and some customers may pay off the system sooner or later.

[xl] The 95% confidence interval is ($127.75, $184.06).

[xli] Minimum product lifetime estimate obtained from d.light product team in laboratory conditions; field conditions may vary

[xlii] Based on consumption estimates generated by the PAT.

[xliii] This estimate represents a best case scenario: it assumes that d.light households pay off their D20g over the course of Year 1 of ownership, that they and comparison customers continue their energy consumption behaviors as reported at endline, that the d.light D20g system continues operating at the same level, and that energy prices remain stable in eastern Uganda. Note that this figure is likely a significant overestimate over longer time periods, as it is unlikely that all of these factors would hold constant over a ten-year time horizon. Additional data collected over time on average useful life of the D20g system in field conditions on energy usage and energy expenditure would be required to make a more realistic projection of future cost savings from owning a D20g system.

[xliv] Note that at the endline survey, 9% reported not having used the system in the past 3 months; this is consistent with a ~10% default rate by customers who cannot sustain payments and therefore discontinue use of the system. This minority group of customers have often experienced a shock to their cash flow or an unexpected situation that requires large cash outlays—for example an illness—making it difficult to continue paying. Similarly, 30% report not having used the system in the past 24 hours; this is consistent with the 10% of defaulters plus 20% of customers who are expected to take a little longer than 1 year to pay off the product and so are not using the product daily.

[xlv] Energy Poverty: How to Make Modern Energy Access Universal? (International Energy Agency, United Nations Development Programme, United Nations Industrial Development Organization, 2010): 17.

[xlvi] Since not every question was answered by each household, this number varies between results. For example, not every household has children, not every d.light household used the D20g system the day before the interview, and in some cases respondents cannot or do not answer every question. There are also instances where house-

holds did not answer questions that were relevant to them, either because respondents did not know the answers, refused to answer, or because of respondent or enumerator error. In cases where there is missing data, both the household with missing values and its matched pair are dropped from that particular result.

[xlvii] Note that these definitions differ from those used by the Grameen Foundation's Progress out of Poverty Indicator (PPI) and USAID's Poverty Assessment Tool (PAT), which characterize kerosene lanterns as high quality.

[xlviii] While this was not the exchange rate during the endline survey (2660.00 UGX = $1 USD on October 27, 2014, the last day of endline surveying), this rate was used for the baseline report, and is closer to the exchange rate during the baseline survey (2457.75 UGX = $1 USD on January 22, 2014, the first day of baseline surveying). Despite currency fluctuations, Ugandan consumers did not experience high inflation during the length of this study and thus paid constant prices in Ugandan Shillings. Converting into US dollars using a fixed exchange rate ensures that the currency fluctuations do not distort the reporting of results, as the exchange rate did not likely have a major influence in the consumer decisions of rural Ugandans.

[xlix] While d.light households were asked about satisfaction with the D20g system using the same ladder, this question was not asked relative to the rest of their village.

[l] (2010) Uganda National Household Survey 2009/10, Socio-Economic Module, Abridged Report, Kampala, http://www.ubos.org/UNHS0910/unhs200910.pdf.

[li] Note that multiplying estimates of average daily per capita consumption by average household size (in Table 2) will not give the same result as the average daily household consumption expressed in Table 2 and below Figure 1. This is because estimates for daily household consumption multiply per capita consumption by the number of household members household-by-household (rather than multiplying the two aggregate averages), and because the other estimates remove outliers (the top and bottom 5% and the top and bottom 10%, respectively).

[lii] Includes lanterns and home systems.

[liii] Bonney J, Canes-Wrone B, Minozzi W. 2007. Issue accountability and the mass public: the electoral consequences of legislative voting on crime policy. Work. Pap., Dep. Polit., Princeton Univ.

[liv] Boyd CL, Epstein L, Martin AD. 2008. Untangling the causal effects of sex on judging. Presented at Annu. Conf. Empirical Legal Stud., 2nd, New York, Nov. 9–10. Available at SSRN: http://ssrn.com/abstract=1001748

[lv] Eggers A, Hainmueller J. 2008. The value of political power: estimating returns to office in post-war British politics. Work. Pap., Dep. Gov., Harvard Univ.

lvi Raessler S, Rubin DB. 2005. "Complications when using nonrandomized job training data to draw causal inferences." Proc. Int. Stat. Inst.

[lvii] Caliendo, Marco and Sabine Kopeinig. (2008) "Some practical guidance for the implementation of propensity score matching." *Journal of Economic Surveys.* 22(1), pp. 31-72.

[lviii] In the context of the propensity score, however, it has been suggested that variables influencing selection into treatment is more important than influence on potential outcomes. See Augurzky, B. and Schmidt, C. (2001) The propensity score: a means to an end. Discussion Paper No. 271, IZA., for more information.

[lix] The Poverty Assessment Tools are short, country-specific household surveys to help determine the prevalence of BPL households in a population of interest. While the primary intent is for these surveys to indicate population-level poverty prevalence, we may also use the household-level PAT scores to indicate likelihood a household is subsisting under the poverty line. For more information on Uganda's PAT, see http://www.povertytools.org/countries/Uganda/Uganda.html.

lx While many statistical tests showed differences between the treatment group and the *full* comparison group at baseline, we want our matching method to give us a comparison group that is *not* significantly different from our comparison group.

lxi The Poverty Assessment Tools are short, country-specific household surveys to help determine the prevalence of BPL households in a population of interest. While the primary intent is for these surveys to indicate population-level poverty prevalence, we may also use the household-level PAT scores to indicate likelihood a household is subsisting under the poverty line. For more information on Uganda's PAT, see http://www.povertytools.org/countries/Uganda/Uganda.html.