Off-grid solar in Kenya: Market potential and development impacts

Impact evaluation Orb Energy Kenya

Synthesis report

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The views expressed in this report are purely those of the authors and may not in any circumstances be regarded as stating an official position of FMO

1 Introduction

Background and aim

In 2016, FMO commissioned Trinomics and its partners ISS and RSA to conduct a rigorous impact evaluation of the development impact of its investment in the Kenyan expansion of Orb Energy. The main research question was: *What are the development impacts of solar home systems in Kenya?* The study focused on measurement of the wider economic, social and environmental development impacts on the lives of beneficiaries. In this way, the study ultimately aimed to help FMO optimise its impact strategy with its off-grid investments in Africa.

Orb Energy & FMO

Orb Energy PTE Ltd is an Indian solar company, established in 2007. It is a manufacturer and distributor of single light lanterns, solar home systems (SHS) and solar water systems (SWS). In 2012, Orb Energy decided to replicate its Indian business model in Kenya. Orb Energy's operations in Kenya started in 2014. In 2015, FMO supported the expansion to Kenya with a USD 2 million equity investment from the Access to Energy Fund (AEF) and in 2017 FMO provided USD 4 million of additional financing to Orb Energy India from the Infrastructure Development Fund (IDF). The initial financing was meant to help covering the costs of rolling out franchised retail outlets across Kenya and establish a centralised distribution infrastructure of the solar products. The follow-on investment aimed to finance the roll-out of the commercial rooftop PV sales strategy (incl. in-house financing to the customers) and strengthening Orb's presence in Kenya by expanding the branch network and increasing manpower.

In Kenya, the main solar products are sold on credit via partnerships with Micro finance Institutions (MFIs), representing more than 95% of all sales in Kenya (from 2014 to first semester of 2017). The main SHS include the four Solectrics as presented in Figure 1-1. Orb Energy also sells other solar products (such as water heaters), but those were not analysed in this study.

Figure 1-1 Orb Energy *Solectric* products

Solectric 10 **Solectric 15** **Solectric 30** **Solectric 120**

Methodology

The methodology for this rigorous impact evaluation was based on a large-scale survey at household level that gathered user experience and household characteristics data for 528 households that bought an Orb SHS and 520 households that did not have an Orb or any other SHS, but were very similar on many other socio-economic characteristics (counterfactual households). The sample of households with an Orb SHS were selected to be representative for the overall Orb client base in terms of location, MFI affiliation and type of solar home system. Using the data gathered from the surveys, econometric analyses were conducted to anayse the differences in outcomes on various indicators between the households with an Orb Energy system and those without it.

2 Users and use of solar home systems

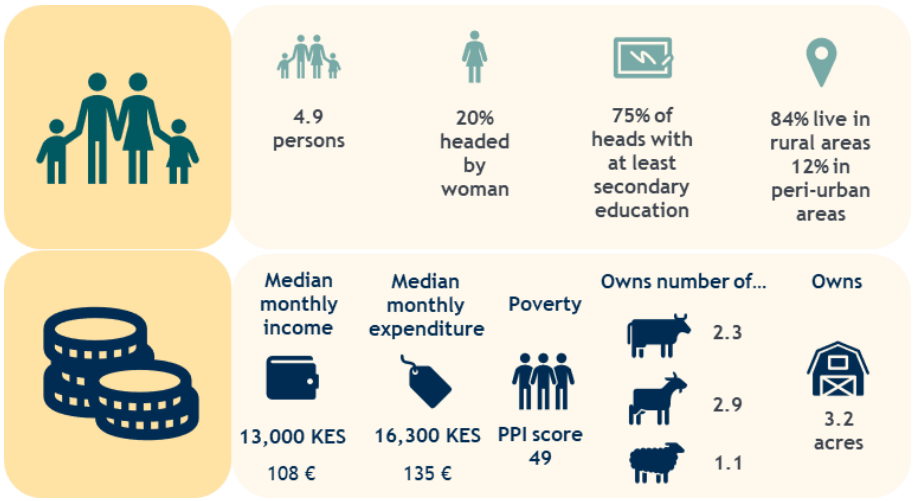
2.1 Who uses solar home systems?

2.1.1 *Main socio-economic characteristics of households with a SHS*

Figure 2-1 Example of a house with SHS

The main socio-economic characteristics of households across Kenya that bought an Orb SHS are presented in the infographic below. The average household has 4.9 members, which typically implies two parents and three children. In one out of five households, the household head is female. In most instances, this implies that there is no male spouse in the household. Most SHS clients live in a house with an iron sheets roof (93% of houses) and walls made of bricks or cement (47%). The walls of most other houses (36%) are made out fo poles and mud (Figure 3-1). Moreover, most households heads (75%) obtained at least secondary education (Secondary 1-3 or higher). Some 22% of household heads have primary education. Only 3% of household heads obtained no education at all.

Figure 2-1 The average socio-economic characteristics of households with an Orb Energy SHS



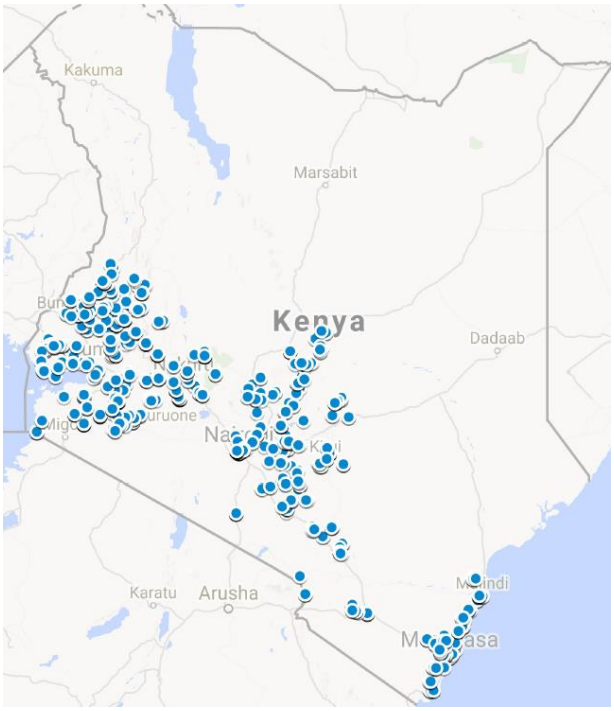
Source: Survey results - 528 treatment households (1,048 obs total)

Note: Using (0.0083 EUR/KES) exchange rate

The average SHS household falls in the 30-40% group if all Kenyans were ranked in terms of wealth

Households with a solar home system earn a median montly income of around 13,000 Kenyan Shillings (around €108) per month. But income for rural households can be difficult to estimate due to the seasonality in their earnings from agriculture. Using average expenditures, we find that most households spend around 16,300 KES per month (or €135). This places SHS households in the 30-40 percentile of the expenditure distribution of Kenya. Therefore, Orb SHS users do not constitute the bottom of the pyramid, but rather the group between the average Kenyan household and the poorest Kenyan households. From the commonly accepted composite index measuring household assets (the Poverty Probability Index - PPI), the chance that an Orb SHS household lives below the $1.9 a day poverty line is 14.4%. As a comparison, some 34% of the entire Kenyan population lived below the $1.9/day poverty line in 2005.

Figure 2-2 Location of survey respondents



Source: Google Maps and survey results

As shown in Figure 2-2, most SHS households live in rural areas (84%). Figure 2-3 shows in more detail the location of the houses of a representative sample of Orb SHS clients across Kenya on the basis of the location of respondents to the survey.[1] Households that buy SHSs are mostly located in Western, Central and Eastern Kenya along relatively well-connected road corridors. The arid north and northeastern parts of Kenya are completely unserved by Orb Energy, but the population densities in these regions are also much lower. This corresponds with the wider off-grid solar, where most suppliers focus on the peri-urban and densely populated rural areas. In line with the location of SHS households, most owners work in agriculture and grow maize, wheat or hold livestock (40% of household heads do and 50% of their spouses do). Most other respondents work in local retail (~15%).

An average SHS household has a 14% likelihood of being poor
(based on PPI of 49 and $1.9/day poverty line)

2.1.2 *Socio-economic characteristics of SHS households*

There are however also considerable differences in wealth between SHS households. Overall, those households that own a Solectric 120 (4 lights & TV) are more wealthy than those that own a Solectric 30 (four lights & radio). The composite poverty indicator (PPI) is 9% higher for the households that buy a Solectric 120 compared to the 30 (the higher the score the more wealthy). Table 2-1 shows that households that own a Solectric 120 can be seen as more 'wealthy' on many other relevant characteristics as well.

[1] Since survey respondents have been sampled representatively from the overall distribution of Orb Energy clients (and the sampling targets have been met), the distribution of respondents across Kenya can be interpreted as the distribution of Orb clients as well. However, less than 5% of Orb clients that lived in more remote regions were not sampled for the survey due to the costs of surveying them.

Table 2-1 Differences in socio-economic characteristics between Solectric 30 and 120 households

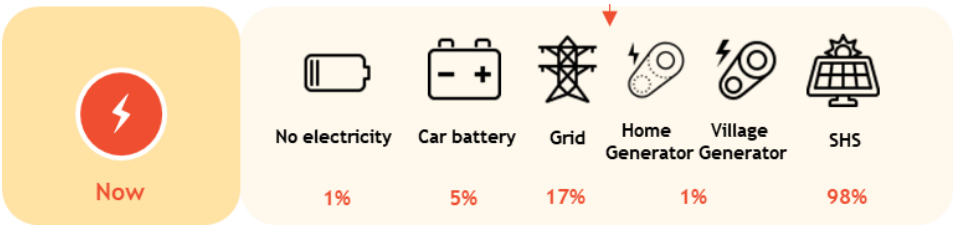
Indicator		Solelectric 30	Solelectric 120	Difference
PPI		48	52	9%
Expenditures per week (Ksh)		4,361	5,917	36%
Number of cows		2.1	2.8	34%
Number of goats		0.9	1.6	73%
Number of sheep		1.5	3.2	111%
Owns acres of land		2.7	4.2	57%
Number of rooms for living		3.1	3.7	20%

2.1.3 *Electricity sources at home*

For most Orb Energy SHS clients, their SHS is their only source of electricity at home[2]. Many still combine the use of the SHS with traditional sources of lighting not based on electricity (see next chapter on impacts). As Figure 2-3 shows, there are also Orb Energy SHS clients that combine the use of their SHS with other sources of electricity at home. Some 17% of Orb Energy clients are also connected to the grid, suggesting that they either use the SHS during black-outs of the grid or as a substitute for electricity from the grid. Another five percent of SHS users also use a car battery in their homes, mostly to power other energy saver or LED lights.

17% of Orb Energy SHS also have a grid-connection

Figure 2-3 Sources of electricity for SHS households



Source: Survey results - 528 treatment households (1,048 obs total)

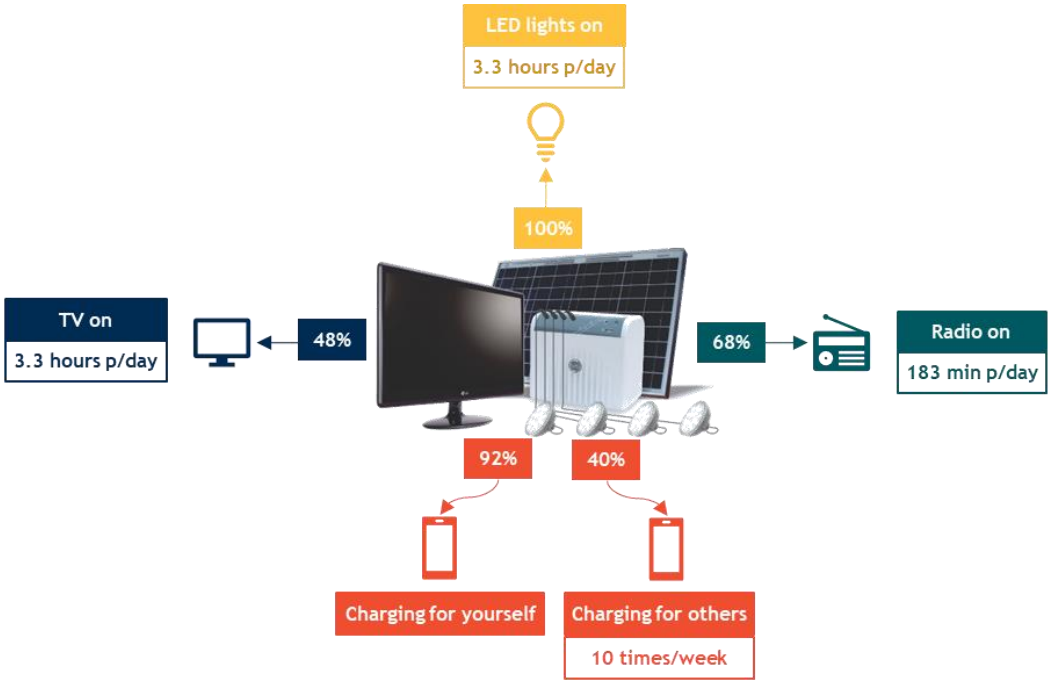
2.2 What do households use their solar home system for?

The use of the Orb SHS differs per type of Solelectric. All Solelectric types provide lighting functionality and all clients indicate that they use the LED lights: on average 3.3 hours per day. According to Orb's product specification, the maximum amount of light per day is 4 hours. Therefore, their clients achieve a rather high average use of the lights, taking into account that on cloudy or rainy days the maximum lighting capacity cannot be reached. All Solelectric types also come with mobile phone charging functionality. Some 92% of the clients also use this feature to charge their own phones and 40% use the feature to charge phones for others (sometimes for a payment). Those that charge for others do so on average 10 times a week. The *30* comes with a radio since the end of 2015, so most of the *30* users have one (48% of surveyed clients have a Solelectric 30, 38% received a radio). The actual share of clients that had a radio was 68%, which means that some households already had a radio. The radio is turned

[2] 1% of the SHS users incorrectly indicated they did not have access to electricity

on for on average 183 minutes per day. Lastly, the *120* comes with a TV and antenna receiver. Some 32% of the surveyed clients have a *120* and some others already owned a TV, which means that almost half of all surveyed Orb clients (48%) had a TV at home. They use the TV on average 3.3 hours per day. The maximum time that the TV can run using Orb's solar power is 3 hours per day. This means that the *120* clients on average use the full capacity of the system to power the TV and that likely those households with access to the grid (16.5% of Orb clients) use the TV even more per day.

Figure 2-4 Use of solar home system



2.3 Are households satisfied with the functioning of their SHS?

According to its clients, Orb Energy delivers a satisfying product and service performance. Nearly all of the surveyed clients (96%) had their SHS installed and operational within one month after purchase. Most of them are also using the SHS actively (92%). Yet, half of the clients (50%) indicate that a problem with the functioning of the device occurred in the past 12 months. Most of them had problems with the battery (24%) and some with the lights or the TV. At the same time, though, 96% of customers did not incur maintenance costs in the past 12 months for the system. This indicates the value of the warranty period (of one year) that Orb offers, in which time ORB resolves problems or defects with the system for free. This period is also important for increasing clients' understanding about the functioning of the system as some customers (still) assign adverse solar weather conditions (cloudy or rainy) to a malfunctioning of the battery as the experiences from focus groups with clients learnt. Overall, the total product-service combination that Orb Energy provides seems to satisfy customers. More than two-thirds of the surveyed households were likely or very likely to recommend their SHS to friends or family.

Figure 2-6 How likely are you to recommend the Orb Energy SHS to friends or family?

3 Development impacts of solar home systems

In addition to the analysis of the off-grid solar market and the market potential, this measured the economic, social and environmental impacts of SHS use. Households that use Orb SHS and an equal number of similar households without SHS were surveyed about several aspects of their daily lives. The differences between both groups can then be seen as the impacts of the SHS.

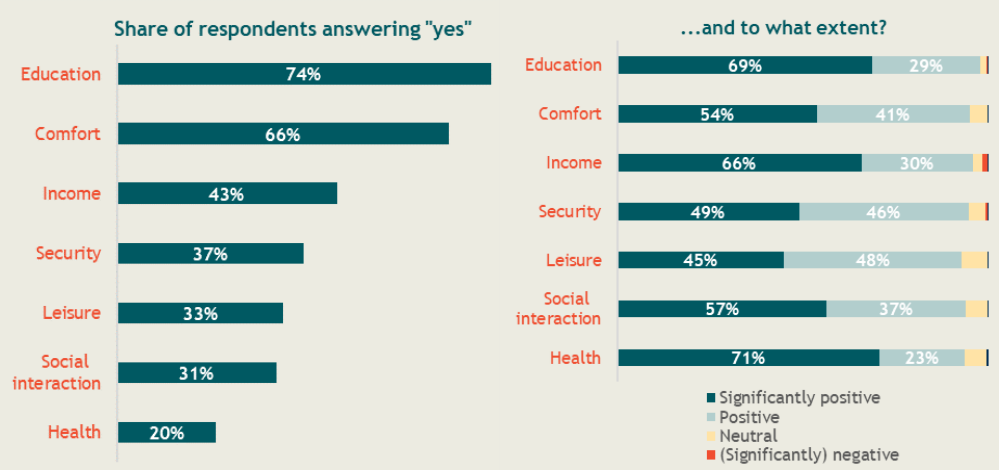
3.1 Use of solar home systems deliver small positive development impacts

The survey focused on how the SHS impacts the income and expenses of households (economic impacts), on how they spend their time (social impacts) and on effects on global warming through a change in emissions (environmental impacts). Evidence from existing literature and the preparatory field trips also suggested possible wider social impacts from the adoption of SHS, such as impacts on security, education levels and health.[3] However, due to measurement challenges in these areas, where effects materialize only in the long term, the impact evaluation captured social impacts only through changes in time spent on daily activities, such as child time spent on studying and TV watching, rather than direct effects on education and health outcomes.

3.1.1 What do Orb Energy SHS users think themselves?

Before we present the results from the econometric impact analysis, we present the effects as *experienced* by the SHS users themselves. According to the majority of them, the use of the SHS has significantly improved their lives. Some 93% of SHS users indicated that the use of the SHS improved their lives either in a significantly positive or a positive manner. Most users indicate that mainly 'education' and 'comfort' levels improved considerably. Some 74% and 66% of all SHS users indicated that these aspects of their lives were impacted positively. Some 43%, 37%, 33% and 31% of SHS users indicated that income, security levels, quality of leisure or social interaction respectively changed significantly. The switch from kerosene lamps to LED lights also improves indoor air quality, but only one in five SHS users mentioned improved indoor air quality to be positively improved. This is an expected result as cooking remains the main contributor to indoor air quality.

Figure 3-1 In which areas of your life did the SHS have the greatest impact(s) and to what extent?



[3] Such as notably Rom et al (2017) who did an RCT with pico-PV in Kenya, but also studies from Bensch et al (2014) in Burkina Faso, Grimm et al (2013) in Rwanda, Furukawa (2012) in Uganda and IDinsight (2015) in Uganda

3.1.2 *Substitution of lighting and climbing the energy ladder*

Before we present the impact results, we present the root causes for the way in which SHSs create an impact for its users. First and foremost, people get access to a different source of lighting. Table 3-1 illustrates that SHS households use on average 40% fewer 'dirty lamps' (kerosene lights, candles and gas lamps) and 48% more LED lights to satisfy their lighting needs. Concretely, this means SHS users substitute their 'dirty lamp' (typically kerosene lights) and other 'clean lamp' (powered by the grid or other batteries) use for SHS light. On average, they put on kerosene lights for 1.8 hours less per day and energy savers for 0.7 hours less. In turn, they use LED lights (from the SHS) for 2.7 hours more than similar households without SHS. This implies all households in the sample use lights for a similar amount of hours per day, but the SHS users replace non-LED lighting sources with their SHS.

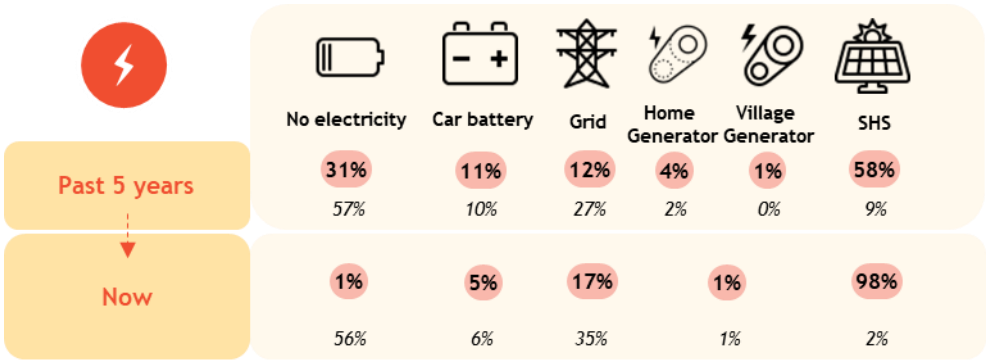
Table 3-1 Change in use of lighting sources

Indicator	Dirty lamp	Clean lamp	LED lamp
Share of lamps used	-40%	0%	48%
Number of lamps used	-2	-0.1	1.8
Hours per day lamps used	-1.8	-0.7	2.7

Climbing the energy ladder

We also find that almost a third of Orb Energy clients did not have access to electricity at all before the purchase of the system (Figure 3-2). On the other hand, more than half (58%) of Orb Energy clients owned (another) SHS prior to the purchase of the Orb system and some 28% of clients also had access to electricity from the grid and/or a generator. Indeed, also the share of non-SHS users that did not have access to electricity remained stable in the same period. As the total does not add up to 100%, there is also evidence for the fact that households mix different sources of energy. In practice, this is most likely from the combination of a SHS and either grid access, a car battery or a generator, or from grid access with a generator (to cover black-outs). This shows that shows that Orb Energy SHS users have climbed the 'energy ladder' as they replaced traditional fuels by modern sources of electricity, while their total use of electricity also increased.

Figure 3-2 Electricity sources at home now and in the past



Note: Red-shaded boxes represent distribution of electricity sources for Orb Energy SHS users; shares in black represent distribution of electricity sources for similar households without SHS (control group).

3.2 Economic impacts

The study tested whether SHS use creates an economic impact at household level: does it impact household expenditures or income?

Impact on expenditures

Since households with a SHS use less 'dirty' lamps to light their homes, they need to buy less fuel (kerosene) or candles to light their home. The on average consumption of kerosene for lighting declines by 1.2 litres a month, saving them on average KES 86 per month. Consumption of candles decreases also a little bit, but not significantly. Moreover, Orb SHS owners need 0.7 fewer batteries per month, translating into savings of approximately 17 Ksh per month (€0.14). Jointly, households therefore save about 103 Ksh per month on energy sources for lighting (approximately 2% of monthly expenditures). Rom et al (2017)[4] find that energy savings from pico-PV lanterns are KES 53-93 per month, or 1%-2% of monthly expenditures. Though lower, we regard these findings in line with our results as their solar products used were smaller than ours and therefore less pronounced savings may be expected.

In addition, SHS users save on the costs for charging their mobile phones. SHS users save on average 44 Ksh per month from not having to charge elsewhere anymore. Next to financial savings, SHS households also spend less time buying the kerosene and batteries they would use without SHS. In total, they save nearly 10 minutes per week. At the same time, though, SHS households spend more on purchasing firewood, which is mostly used for cooking. They spend between 193-258 Ksh more per month than non-SHS households. There is no easy explanation for the relation between SHS ownership and this increased consumption of bought firewood, but the most likely cause is measurement errors during data collection.[5] The overall impact of SHS ownership is therefore an increase in energy expenditures of 46 - 111 Ksh (€0.38 - €0.90). However, not taking into account the (uncertain) effect from the change in firewood consumption, energy expenditures (save cooking) decrease as result of SHS ownership.

Table 3-2 Impact SHS on expenditures

Item	Unit	Impact (Ksh)
Kerosine consumption	-1.2 *l* p/m	-86
Batteries for radio	-0.7 p/m	-17
Charging mobile phone at home		-44
Sub-total savings		***-147***
Consumption of firewood	2 bundles	193 - 258
Sub-total extra expenses		***193 - 258***
Total impact on expenditures		**+ [46 - 111]**

Most equivalent impact evaluations conducted to date in Africa also find a reduction on expenditures for energy, but the magnitudes vary. IDInsight (2015)[6] finds that D-Light systems lead to less energy expenditures ($5.6 per month) and so do Grimm et al (2016)[7], though with a lower effect ($1 per month). As mentioned, Rom et al (2017) in Kenya find a reduction of less than $1 per month. Bensch et al (2015)[8], on the other hand, find an increase in expenditures for energy sources (~€6.3) per month as SHS users enjoy the increased scope of energy services and increase their aggregate expenditures on

[4] Rom, A., Günther, I., Harrison, K., 2017, The economic impact of solar lighting: results from a randomised field experiment in rural Kenya, published by ETHZüich, Acumen, SolarAid and Google, February 2017
[5] According to the enumerators recording the survey results, the units in which firewood is bought varies strongly across the country (for example bundle sizes differ strongly). Even though the data cleaning excerise focused on standardising the measurement unit, and enumerators were also specifically instructed on this indicator, it is likely that some measurement issue remained as the standard deviation around the mean of firewood consumption is significantly higher than for other variables. Outliers were removed.
[6] IIDinsight, 2015, d.light Solar Home System Impact Evaluation, published by USAID/Shell Foundation/UK Aid
[7] Grimm et al. (2016) A First Step up the Energy Ladder? Low Cost Solar Kits and Household's Welfare in Rural Rwanda, World Bank Economic Review
[8] Bensch, G., Grimm, M., Langbein, J., Peters, J., 2015, Impact Evaluation of NL Supported Programmes in the area of Energy and Development Cooperation in Burkina Faso: The provision of solar energy to rural households through a fee-for-service system

energy. We should also note that kerosene prices have an important effect on the comparison of impact results. During our survey period, kerosene prices across the country varied between KES 60-70, while in 2014 and 2015 the prices of kerosene have been around KES 40[9].

Impacts on income

We tested also whether SHS ownership led to a change in income generating activities. However less than 1.5% of Orb Energy clients use the SHS for income generating activities, which is not significantly different from non-SHS users. A SHS user does charge mobile phones for others more often (on average 1.6 times) than non-SHS users, but there is also no sign of significant income resulting from that. Moreover, SHS users do not spend more or less time in income generating activities. However, we do find that SHS households have a significantly higher income than similar non-SHS households and 43% of SHS users mention *income* as an area of their life that was impacted (mostly positive) by the SHS (Figure 3-1). Due to this mixed evidence, we cannot conclude whether SHS ownership has an impact on income.

Overall economic impact

In total, SHS users save about 147 Ksh per month, or 1,764 Ksh per year, on energy for lighting. Compared with the cost of the most popular Orb SHS, the Solectric 30 at 12,990 Ksh (retail price in 2017), this implies that the savings on energy expenditures will pay back the system in 7-8 years. According to Orb Energy, the battery of the SHS has an expected life of about 5 years, the lights 10 years and the panel approximately 15 years. We cannot, however, conclude from this simple pay-back calculation that buying an Orb Energy SHS is not a rational decision as non-monetary benefits are not taken inot account (discussed next). Moreover, this calculation depends on the price of kerosene (KES60-70 during the survey period), which has shown to fluctatute strongly in the past years, as well as the price of the SHS. At the time of publishing (Jan-2020), for example, the price of the Solelectric 30 had dropped to 10,990 Ksh and the price of kerosene has steadily been increasing to on average 90 Ksh in 2018 and 100 Ksh in 2019. [10]

3.3 Social impacts

The social impacts of a SHS could have many dimensions. Existing literature and findings from preparatory field trips showed that households might experience impacts in the field of security (by being able to light their homes at night), leisure (better being able to host friends or family, better able to read, watching TV and listening to radio), health (from improved indoor air quality due to the substitution of kerosene lamps) or woman empowerment. About a third of Orb Energy SHS users indicated that their lives had improved in these areas of security, leisure and social interaction by the use of the SHS (Figure 3-1). However, such impacts are very hard to measure quantitatively (what are the right indicators?) and existing literature that did try did not find significant impacts[11]. Therefore, we focused on measuring the social impact of the SHS on time spent by household members on various activities and its associated impacts in this study.

[9] http://www.oilnewskenya.com/maximum-retail-prices-for-fuel-in-major-towns-kenya-may-15th-to-june-14th-2017/
[10] https://www.the-star.co.ke/business/kenya/2019-04-05-kerosene-prices-jump-17-in-2018-on-new-excise-levy/
[11] For example, Bensch et al (2014) do not find an impact of SHS ownership on woman empowerment and IDinsight (2015) did not find an impact on coughing or health effects

Orb Energy SHS increase the level of living comfort

The key result found in this study is that the ownership of a SHS increases the level of living comfort. Firstly, Orb Energy SHS users rate the quality of lighting at home with almost one point higher on a scale from 1-5 compared to households without SHS (4.4 with versus 3.6 without SHS). Moreover, the total number of lighting hours increases by approximately 20 minutes per day. Secondly, spouses of the head of the household spend 30 minutes more per day on watching TV. Even though other free time reduces by about 15 minutes per day, the additional TV watching is generally experienced as pleasurable way to spend free time in Kenya. Also children watch somewhat more TV (some 10 minutes extra per day) than their counterparts in families without SHS. But children with SHSs at home do not spend more time studying at home than others without a SHS at home. This result was unexpected as many solar companies claim this as a significant positive effect from SHS ownership. Similar impact evaluations however also do not find increases in overall time spent studying by children. Only Rom et al (2017) find that boys spend 17 minutes longer studying at home. Girls however, were not found to study longer.

On the other hand, SHS users indicated that their lives improved mostly in the area of 'education' (see Figure 3-1). This could be because the *quality* of studying at home however improves due to the better quality light (brighter and cleaner). They could also consider the effect of the TV, which they watch more longer, as a form of education as it also a way to gather information or increase knowledge.

3.4 Environmental impacts

SHS users largely substitute fuel-consuming lamps by the LED lights from the SHS to light their homes. The effect is that fuel-consuming lamps are used 1.8 hours per day less by SHS users. Most households without a SHS use kerosene lights. The use of kerosene for lighting by SHS households therefore declines by approximately 14 litres a year. Burning kerosene creates greenhouse gas (GHG) emissions equivalent to 71.9 CO_2 equivalents per Tera Joule. Using a SHS, on the other hand, does not create GHG emissions (those created during production of equipment not taken into account). Therefore, a household with an Orb Energy SHS in Kenya saves on average 0.0368 tonnes (36.8 kilograms) of CO_2 equivalent emissions per year.

An Orb Energy SHS household in Kenya saves on average 0.0368 tonnes (36.8 kilograms) of CO_2 equivalent GHG emissions per year

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