PAY-AS-YOU-GO SOLAR PV IN RWANDA:
evidence of benefits to users and issues of affordability

Simon Collings
Director of Learning and Innovation, GVEP International
simon.collings@gvepinternational.org

Anicet Munyehirwe
Consultant in Energy and Renewable Energy, Inclusive Business and Consultancy (IB&C) Ltd

Indigo Duo Solar Home System
Source: Azuri Technologies

Simon Collings is the author of a number of studies on energy access. He joined GVEP in 2003. Anicet Munyehirwe is an independent consultant with extensive experience of researching energy sector issues in his native Rwanda. Anicet conducted the baseline and end of project studies described in this paper. GVEP is a non-profit organisation which provides advice and technical support to businesses involved in off-grid energy supply in sub-Saharan Africa.

KEYWORDS

- OFF-GRID ELECTRIFICATION
- SOLAR HOME SYSTEMS
- PAY-AS-YOU-GO SOLAR PV
- RWANDA
- ENERGY FOR ALL

In 2013 Azuri Technologies, a provider of solar home systems, entered the Rwanda market with USAID support. During project implementation various distribution challenges were encountered and useful lessons learned. Impact studies were conducted which showed households using the Azuri systems benefiting from significantly more hours of light and from the ability to charge phones at home. These households were among the wealthier segments of the rural population indicating affordability challenges for some households.

INTRODUCTION

Azuri Technologies is a company headquartered in the UK which provides pay-as-you-go (PAYG) solar PV home lighting products to customers in off-grid areas of sub-Saharan Africa. In May 2013 the company entered the Rwanda market with financial support from the USAID Development Innovation Ventures programme. According to World Energy Outlook 2014 only 17% of Rwanda's 10 million people have access to grid electricity. In rural areas the electrification rate is 5%, one of the lowest in sub-Saharan Africa. The product provided by Azuri is called Indigo Duo. It consists of a power unit using a lithium iron phosphate battery, a 2.5W solar panel, two light points using LEDs, and adapters to enable the user to charge a phone. Customers pay an installation fee of RWF 6,600 (approx. USD 8.80, though currency degradation was a factor throughout the project) and the rest of the cost in regular 28 day instalments RWF 3,500 (approx. USD 4.70). Each Indigo unit has a key pad which is used to enter a code provided to the customer when they make a payment. If payments are not made the unit switches itself off. After an agreed payment period (21 instalments or 84 weeks) the customer can unlock and own the system by paying a single "unlock fee" of RWF 6,600. Customers "top up" either by purchasing scratch cards which provide a number they can use to obtain a top up code via SMS, or through mobile money payments.

Azuri partnered with GVEP International, an NGO which provides support to SMEs working in the energy access field. GVEP's role was to help identify a local distributor, and provide training, support and advice to the distributor. GVEP also commissioned and supervised a

baseline survey at the start of the project which helped determine the pricing strategy. An impact study was later conducted to assess the benefits experienced by households using the Azuri product. The impact study included a socio-economic profile of Indigo users relative to the general off-grid population.

LITERATURE REVIEW

Previous studies have been conducted on the impact of solar home systems on households in several countries including Bangladesh (Khan et al., 2014), Indonesia (Djamin et al., 2002), Zambia (Gustavsson and Ellegård, 2004), and Kenya (Jacobson, 2007). Data on the impact of these types of products, particularly in sub-Saharan Africa, are however scarce and most pre-date the arrival of pay-as-you-go products. The studies which do exist generally show improved quality of lighting and economic benefits from reduced expenditure on kerosene and batteries. Evidence of impact on children's education is mixed.

One study, a randomised control test examining the benefits of pico-solar lamps in Rwanda, is of relevance to the present paper (Grimm et al., 2015). This research found that adoption of small solar lanterns significantly reduced household expenditure on dry cell batteries and kerosene, and improved air quality in the home. The researchers found no overall increase in the time children spent in studying each day, though there was a switch of study time from daylight hours to the evening. There was some increase in the time women spent on housework in households using the lamps, and a reduction in leisure time. Also of interest is a study of the impacts of mini-grids in Rwanda conducted as part of the GIZ programme supporting mini-hydro developers which provides some relevant information (Bensch et al., 2010). This study used data from existing mini-grids to predict likely impacts in areas where new sites were to be developed using propensity score matching (PSM) techniques. No study of the impact of solar home systems in Rwanda has been published that we are aware of.

1. THE PROJECT

Azuri Technologies' business model relies on partnerships with in country distributors. In the case of Rwanda a number of potential distribution partners were investigated and negotiations were held with two local companies, both involved in distribution of solar lanterns. The selection criteria was based around their reach into rural communities and access to last mile distribution, experience in solar lighting and interest in developing a service based offering for their business. The business eventually contracted to manage distribution is a Rwandan company based in Kigali and employing around 4 staff. Prior to engaging with Azuri the company had been selling retail solar lanterns, primarily serving the Northern and Eastern provinces. Normally Azuri would require a distribution partner to pay in advance for the supply of goods. In the case of the USAID funded project the grant covered the initial costs of the manufacturing and shipping, so the distributor only paid for product as it was sold. The revenue generated from this activity covered Azuri's costs associated with the implementation of the project. The product is promoted by mobile sales agents who visit the various target communities and acquire customers (typically around 100 customers per agent). The mobile sales agents are in charge of the installation of the system. The solar home systems should not need regular maintenance beyond keeping the solar panels clean (customer instructed how to do this) and replacing the battery after a few years. In case of a technical problem, the customer has a helpline to call to report the fault. The customer service team goes through a series of questions to establish whether there is a fault or whether the problem can be easily fixed (the panel having come unplugged or a LED having failed). If the unit is faulty, it will be replaced. The sales agents in this case would deliver the new unit and collect the faulty one.

The project identified several challenges in the execution model and the technical capabilities of the product. A number of these were addressed within the project. Unlike some other markets in which Azuri operates, a significant number of households in Rwanda have more than 2 rooms, indicating that a larger product with more lighting capacity would likely increase the impact of the solar home systems, and consequently reduce the consumption of alternative lighting sources.

In some areas where systems were installed long periods of overcast conditions reduced the charge generated thereby affecting the available power/run time. Next generation products are now fitted with oversized solar panels to address this issue. The main technical issue experienced by the product was intermittent faulty switches in a proportion of the units. This manifested as a flickering of the lights due to contact resistance developing in the in-line switch. Later units shipped to the project had a higher quality switch as standard and a supply of these new switches has been provided to the distribution partner to address issues in the installed base. In future products, mechanical switching has been eliminated and replaced with digital switching.

One further product improvement has been established – the use of greater levels of "tamper proofing" for the devices, both in the electronics and the packaging to make it considerably more difficult to tamper with the unit.

Because of the limited development of mobile money services in Rwanda, the project initially utilised physical top up cards (scratch cards,

available from the distributor's sales agents) as a mechanism for customer payment and validation. The customer purchases a top up card, scratches off the covering to reveal a code that is then sent along with the customer's unit serial number via SMS to an in-country gateway. The gateway then contacts the Azuri server which validates the numbers and generates a top up code which is unique to the customer's system. This is sent back to the customer via SMS. This payment validation method has the advantage that it is broadly similar to airtime purchase, so does not require extensive modification of customer behaviour, can be readily set up and requires limited in-country infrastructure to execute. This allows relatively rapid business development and does not tie the technology to a specific mobile service provider. As the product does not have an integrated mobile phone module the build cost is lower and deployment location is less constrained as the customer does not need to have a mobile signal inside the house at the point where the unit is installed, he or she merely needs to be able to send a text message once a week.

However, there are a number of disadvantages to a physical top up card system that provide some challenges and, in the extreme, limit its effectiveness and long term scalability. The major issue is the in-country logistics to manage and distribute physical cards to the target rural communities, which in the case of reasonably disbursed population in mountainous terrain, can require considerable time and expense. Local agent networks also need to be sufficiently integrated into the distributor's organisation to manage physical cash and flow this back to the distributor (and onwards to Azuri). In the case of the project there were significant challenges in ensuring adequate and timely disbursement of funds from agents back to distributor. Whilst this can be mitigated by a debit-approach (agents must first purchase the cards themselves), this introduces a cash-flow element to another layer in the distribution chain. These issues proved to be problematic for the local distribution partner, despite significant intervention attempts by the project partners, and hence led to intermittent supply of cards to agents and end users in some areas.

During the course of the project steps were taken to trial mobile money solutions. Initially this involved integrating a mobile money system into the Azuri server to provide real-time service to the customer – .e. the customer could initiate a payment from their phone and receive a top up code back in a fully automated manner. This service was due to go live when changes with the mobile money platform led to failure of the integration (from the mobile operator's side). This remains an ongoing issue and illustrates the "single point of failure" that can exist with mobile money platforms, particularly in the situation where a PAYG provider is tied to a single Mobile Operator. Azuri is in the process of broadening the number of mobile money platforms it is integrated into to offer customers maximum choice and reduce dependency on a single provider. Unfortunately, the sophistication of the systems currently available in Rwanda is significantly lower than systems available in Tanzania and Kenya. This is a rapidly evolving area and will be the direction for future deployments, but for the course of the current project a robust integrated mobile money offering was not available.

In the meantime the project developed a more "manual" mobile money system that allows customers to purchase top ups either directly from the distributors office or via their agent, but without the need for physical cards or cash handling. This requires access to a mobile money account (either at customer level or agent level) but not the fully integrated service. This was fully supported by the project partners, with dedicated teams set up and trained to assist the distributor.

One of the most important lessons learnt in the project was around the scalability of smaller distribution partners. The project encountered significant issues when working with the local distribution partner as the project started to scale. This is reflected in the slower than planned ramp of deployment and some of the issues with cash flows in the field. These problems were encountered despite a significant level of in-country support from GVEP, and resource from Azuri (both directly from Azuri employees and from in country support managed by Azuri). The requirement for an active management in country (and at the last mile) of the installed base of customers means a significant "post-sale" commitment is required to ensure reliable customers and reliable cash flows. This is a significant change for most retail based businesses and whilst this is reflected in lifetime revenues achievable, it does require a certain level of structure, organisation and process to be put in place in partner organisations. By their nature, larger organisations or those already providing services tend to have a more process driven business model and so may adapt better than smaller retail-based organisations. In the case that a new organisation is being created to support the deployment of PAYG systems, a common understanding about resource requirements needs to be in place from day one with an adequately resourced growth plan.

During the course of the project, agent training and communication to the customer was highlighted as a key area for improvement. Despite a number of initiatives, a train-the-trainer model was only partially successful, as evidenced by the issues raised by customers around knowledge of the payment scheme and term. In some areas solar panel positioning was sub-optimal, and in some other areas there was a lack of understanding and over expectation on the part of the customer about how the product would perform in certain seasons (due to overcast conditions for extended periods, reducing the charge generated which reduced the available power/run time). A number of the issues highlighted in the end line survey around remaining balance and messaging have been addressed, with improvements in the local language SMS text and a technical change to SMS messaging to ensure every communication around top ups includes a remaining balance to unlock as standard.

Finally, during the course of the project a number of changes were made to import regulations in Rwanda. These had considerable impact as changing requirements were not always communicated or were

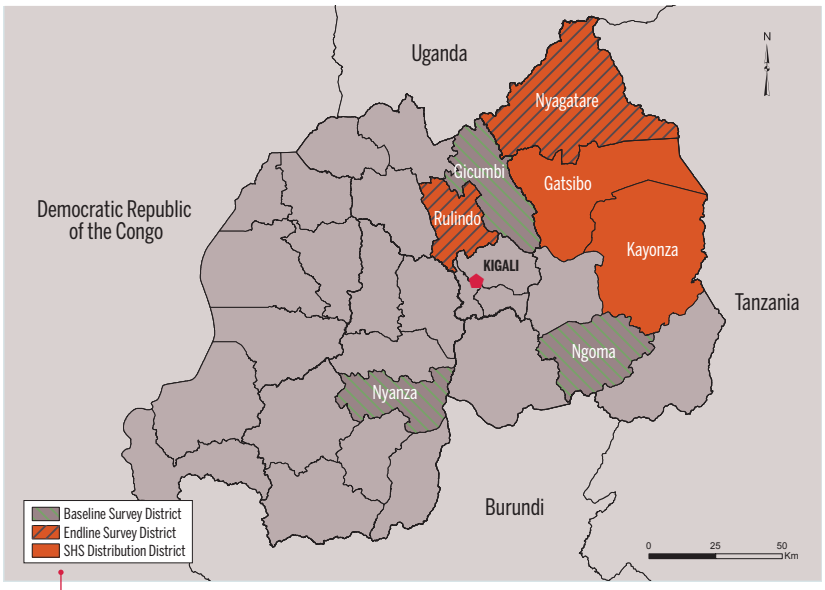

Figure 1. Survey and distribution districts - Source: FERDI

implemented on rapid timelines such that goods in transit fell foul of the newer regulations. Examples include the introduction of pre-shipment inspection and sudden changes in VAT regulations. Given the long shipment times (up to 3-4 months for a shipment to travel from Malaysia to Kigali was not uncommon) the requirement for sensible timescales for changes is key. Ultimately the project partners were able to resolve these changes without significantly changing the underlying economics for the project, but there were considerable delays which had impact on deployment rate and project momentum.

Because of these various factors roll-out of the units proceeded more slowly than originally planned. The project had a headline aim to deploy 10,000 PAYG solar home systems in Rwanda. At the time of project completion in September 2015, ~5,100 units had been deployed (in Nyagatare, Gatsibo, Kayonza and Rulindo districts), 2,800 were in stock awaiting deployment and 2,100 were in transit to Rwanda (stocking levels were managed so as to not overwhelm the local warehousing capability). Azuri expects the remaining units to be deployed over the next 6-9 months. It is worth noting that a period of a year or more to get distribution operating at a significant rate is not uncommon.

Of the units deployed 100 had been unlocked by project end (reached the end of the PAYG period). Given the term of the PAYG period and project timelines, this is higher than expected and reflects that a proportion (70%) of the unlocked units were unlocked early – i.e. the customer accelerated the payment plan to reach the end ahead of PAYG schedule.

2. BASELINE RESEARCH

The Azuri project started in May 2013 and a contract was signed with a local distributor, in late October 2013. The first units were distributed in January 2014. The baseline study was conducted in October 2013 prior to any sales activity, and took place in three districts: Gicumbi, Nyanza and Ngoma districts. These districts were purposively selected as places where sales and marketing activity was likely to occur based on the preliminary discussions with potential distributors. Within these districts the study targeted rural areas with no electricity connection.

The study used a multistage sampling technique to determine households to be interviewed. The sample frame for the survey was the list of households in all the targeted rural areas in the districts of Gicumbi, Nyanza and Ngoma. The primary sampling units in this study were the villages in each district as they are the smallest administrative entities in Rwanda. The sample size was 480 giving a confidence level of 95% for a margin of error of +/- 5%.

- A list of all villages in the three chosen districts was obtained from the National Institute of Statistics in Rwanda;
- Urban and peri-urban areas were excluded from the list;
- From the remaining villages, 5 villages in each of the 3 districts were randomly picked using Excel; that is 15 villages in total for the study;
- Within each village 32 households were selected for interview;
- Based on the total number of the households within each village provided by local authorities, a sampling interval was established for each village giving the number of households that each enumerator should jump. For example, for a village of 200 households a sampling interval was estimated to 6 given by 200/32.

Table 1 provides the list of the villages randomly picked and the number of interviewed households.

Table 1. Sample distribution of the baseline survey

DISTRICTS	GICUMBI		NYANZA		NGOMA	
Selected villages	Sunzu	32	Buhoro	32	Karenge	32
	Rwinyana	32	Nyagatovu	32	Kavumve	32
	Kabingo	32	Shinga	32	Bukokoza	32
	Matyazo	32	Kamushi	32	Akinteko	32
	Kabeza	32	Nyabinyenga	32	Kibimba	32
Total per district	160 households		160 households		160 households	
TOTAL	480 households					

"ON AVERAGE THE MOBILE OWNERS HAD TO SPEND 3 HOURS AND 22 MINUTES TO GET THEIR MOBILE PHONE CHARGED."

Primary data were collected using a semi-structured pre-tested questionnaire administered by eight trained enumerators using the local language. Household interviews were conducted during the period of 4-12 October 2013. The household questionnaire captured data on households' demographic and socio-economic characteristics as well as data on the use of different sources of energy for lighting and mobile phone charging.

The survey found that the most commonly used lighting devices were home-made LED devices (DIY) powered by batteries (51% of households used these), tin lamps which use kerosene (41%), but also other sources like mobile phones (24%), candles (11%), hurricane lanterns (5%), and firewood (5%). Households generally use multiple devices and the average amount of light daily was assessed as approximately 2 lighting hours.

Rechargeable LED lamps, solar lamps and lamps using biogas were used by only 1-2% of households. Where they are used they appear to provide superior lighting. Solar and rechargeable LED lamps ranked 1st and 2nd regarding longevity of use with 3 and 2.5 hours per day respectively.

Thirty-five percent (35%) of the surveyed households have children who are studying in primary and/or secondary schools. These children mainly do their homework at home, and 54% of households with children in school said their children study at night. Twenty-nine percent (29%) of the respondents said they put on light when their children are studying and doing their homework. The DIY and tin kerosene lamps are the main lighting devices used for children's education and the indicated average time children spent studying was 1 hour and 10 minutes.

Fifty-five percent (55%) of surveyed households own at least one mobile phone and use it for more activities than calling and sending SMS. They are used for lighting for an estimated 50 minutes per day, and for 1 hour per day to listen to the radio. Mobile phones are charged from small shops in the community which supply general products, and from barbershops. Currently car batteries, grid electricity and sometimes solar energy are used for charging mobile phones. On average the mobile owners had to spend 3 hours and 22 minutes to get their mobile phone charged. This included the average walking time of 37 minutes to get to the charging place and 2 hours and 45 minutes needed for charging mobiles. About 20% of phone users reported that their phones ran out of battery twice a week and batteries could be flat for 15 hours. Sixty-four percent (64%) reported that there was a high risk of the mobile phone and/or batteries being stolen when charging mobile phones outside of the house.

The average weekly expenses for lighting for households that did not have mobile phone was RWF 392 (approx. USD 0.60)[1] while the households that own a mobile phone paid an average of RWF 680 (approx. USD 1) per week for both lighting and mobile phone charging. The average amount that each household said they would be willing to pay for a product which combined lighting and phone charging functionalities with weekly payments, such as the Indigo unit, varied depending on whether the household owned a phone, and on the types of lighting devices currently used. Thirty-three percent (33%) of households surveyed said they would pay RWF 1,000 (approx. USD 1.50) per week for such a product. Households with at least one mobile phone were willing to pay RWF 762 (USD 1.10) compared to RWF 505 (USD 0.75) for households without a phone. Forty-two percent (42%) of phone owning households were willing to pay RWF 1,000 (USD 1.50) per week. Households which use phones as a source of lighting also showed a high willingness to pay for Indigo or a product like it. Drawing on the findings of the baseline study the weekly fee for the Rwanda market was set at USD 1.20 with a payment period of 21 months.

3. IMPACT RESEARCH

In the original project design it was envisaged that most of the Indigo units would have been installed by the time the impact study was conducted. The goal was to install 10,000 units to create a viable scale of business for the local distributor. To evaluate the impact of the units the team had planned to randomly select a representative sample of Indigo users, and a control group of non-users with similar socio-demographic characteristics. This sampling was expected to take place in the districts where the baseline research was conducted.

Ultimately, the research plan had to be modified. After completion of the baseline, a distributor was ultimately selected whose footprint and access to last mile sales and marketing networks were chiefly in alternative areas to those indicated at the time of the baseline study. Consequently, the sales and marketing activity took place in different areas from those where the baseline was conducted. This was not a major issue as the baseline was designed to be statistically representative of the off-grid population in general.

More challenging was the slow growth in sales and problems encountered by the local distributor. Because of the low pricing necessary for the product to be affordable to the target customers, the margins on the product were thin and the distributor and agents found it difficult to make money. Customers initially were fairly dispersed and therefore expensive to service as agents would have to navigate rural terrain. Consequently, some customers could not access the scratch cards easily and fell "out of credit". In some locations attempts were made to unlock the units through tampering with the security systems in the units. As the business scaled, the distributor struggled to support customers and basic processes

1 The exchange rate used here is that prevailing at the time of the study (USD 1=RWF 670).

such as new customer registrations, customer follow up, and scratch card management broke down. Additional resources were provided by Azuri, and GVEP staff helped rebuild processes and clean up a backlog of data entry and customer queries with funding from the USAID grant. In light of these challenges USAID agreed to extend the project by six months.

At the time of the impact survey in May and June 2015 only 3,306 units had been deployed and there was still much work to be done to improve the local distributor's execution of customer support. Units were being repossessed from customers who had been out of credit for a long period (customers are considered in default if they are more than 28 days with no credit on the system) or who had tampered with the product. Supply of scratch cards to customers was still patchy and an alternative "top up" method where customers could use mobile money to pay was being implemented.

In the circumstances it was clear that random sampling of Indigo users would include many who had periodically been out of credit or had encountered other issues with the product, thus making it difficult to obtain robust data on the full impact of the product. Focusing purely on those customers who were known to have been always in credit would not have provided a representative sample of all Indigo customers. Securing the cooperation of customers, especially those who had experienced frustration with the product, could not be guaranteed. In consequence, it was decided to conduct a qualitative study, using a smaller sample size than originally planned, to provide a picture of what customers were experiencing and how they were using Indigo.

3.1. METHODOLOGY

The impact survey compared customers and non-customers with similar characteristics in areas where a large number of systems had been sold. Indigo users tend to be wealthier than most of the rural population, thus to understand any potential impact the study needed to draw comparisons with households with the same socio-economic profile. In some areas a comparison of the data from the baseline with those from both Indigo users and the control group were made in order to check consistency across all the data available. By end of April 2015, a total of 3,306 Azuri units were registered as sold in the database from the Azuri server. Of these 1,792 units were distributed in two districts, Rulindo and Nyagatare, which corresponded to 54% of all units installed. These districts were selected for sampling.

A sample of 100 Indigo users was randomly selected from customer records. For this treatment group of Indigo users a similar sized control group of non-users was identified during the field work, with enumerators identifying neighbouring households with similar characteristics. The socio-economic indicators used included types of housing (cement floors, tin roofs), phone ownership, the occupation of the head of household, ownership of house, animals and other assets. Each Indigo user was paired with a corresponding non-user making a total of 100 users and 100 non-users. In order to minimize the risk of having non-users that were not exactly matching with the users, 10 additional control households were added, increasing the targeted number of non-users that were to be interviewed to 110.

As anticipated, securing the cooperation of customers proved to be challenging. From the sample of 100 customers, the evaluation team managed to reach 78 users. Among the 22 Indigo users who were not reached 13 had agreed to be interviewed but subsequently refused to pick up calls, or had their phones switched off, or were not at the locations provided. Despite repeated attempts to contact these individuals no response was obtained. Three did not have any contact phone number and no one in the neighbourhood or among the agents knew the listed individuals, 3 were registered within two targeted districts but in reality they were living in other districts and 2 were duplicated on the interview list. In one case the customer declined to be interviewed. To establish a matching group of non-users, 88 control group interviews were conducted.

The survey was carried out using a questionnaire which was essentially a repeat of the baseline but with additional questions for Indigo customers relating to product performance and the quality of after sales support. The questionnaire was field-tested to ensure its usability and confirm the quality of the data gathered. Interviews took place during May and June 2015. For each household socio-demographic data were captured, such as age, gender, income, location, education level and occupation of head of household, household size, and assets owned. This information was useful to create a profile of Indigo customers relative to the rural population at large.

3.2. RESULTS

The impact survey findings reflected shortcomings in the distributor's sales and customer support operations. Fifty-two percent (52%) of the Indigo customers reported that they had been out of credit at least once since acquiring the unit. The main reasons were the unavailability of scratch cards, lack of money, and misunderstandings about the date of credit expiry. Forty-four percent (44%) of Indigo users reported experiencing a "technical" problem while using Indigo. Among those customers that encountered technical problems, 43% said that the light was "not bright enough" while 32% complained about lamps that "cut out". Problems with the battery and the switch were reported by 6 and 4 % respectively.

Further investigation following completion of the survey showed that, in many of the cases, "technical faults" were related to a lack of sufficient charging in cloudy conditions and the associated reduced run-times, which are not actual faults in the equipment, but rather stem from either installation challenges in finding an optimal placement for the solar panel, or due to local microclimates leading to insufficient insolation and thus reduced charging of the battery. This indicated a lack of customer education about the capabilities of the product (such as performance differences in the rainy season) rather than actual

technical faults and pointed to a requirement for improving agent training. For those that reported problems to customer support, only a half had seen these resolved. These and other findings proved useful in helping to improve the overall levels of service delivery.

Six types of lighting devices accounted for most of the lighting in both treatment and control households. These include Indigo (treatment group only), torch lamp, mobile phone, candle, DIY lamp and traditional tin lamp (known as "Agatadowa" and powered by kerosene), see Table 2.

Out of 78 households using Indigo 17 (22%) are using Indigo only while 61 (78%) use other devices alongside Indigo. 34 (44%), 8 (10%) and 19 (24%) are combining Indigo respectively with 1, 2 and 3 other lighting devices. For the control group 36 out of 88 (41%) of the households use a single type of lighting while 7 (8%) and 45 (51%) are using 2 or more lamps. The most commonly used devices apart from Indigo were torches, candles and mobile phones. This finding is to a degree consistent with the baseline study which found that households typically owned from 1-4 lighting devices, though DIY lights, tin lamps, and mobile phones were the most commonly used. The widespread use of torches in the control and treatment groups may reflect the relative affluence of these households.

Table 2. Primary sources of lighting for Indigo users and the control group

	USERS OF INDIGO				NON-USERS			
Types of lamp	On its own	With other devices	Total	% of the hhs using each device	On its own	With other devices	Total	% of the hhs using each device
1. Indigo	17	61	78	100				
2. Lamp torch		30	30	38	14	24	38	43
3. Candle		22	22	28	6	16	22	25
4. Mobile		25	25	32	4	24	28	32
5. DIY lamp		3	3	4	5	12	17	19
6.Traditional lamp (kerosene)		**9**	**9**	**12**	**4**	**8**	**12**	**14**
7.Hurricane lamp (kerosene)		**1**	**1**	**1**	**1**	**4**	**5**	**6**
8. Nuru lamp		3	3	4	1	4	5	6
9. Solar lamp		5	5	6	1	1	2	2
10. Rechargeable lamp		3	3	4	5	5	10	11
11. Firewood		1	1	1		1	1	1

The treatment and control groups were asked about purchases of energy sources during the week before the interview. For both treatment and control groups, dry cell batteries, candles and kerosene for lighting were the most frequently purchased items. The percentage of households that did not buy lighting fuel during the week prior to interview was bigger for Indigo - 40% against 28% for the control. This reflects the fact that Indigo is typically topped up monthly (28 day top up precisely), but also suggests that households with Indigo use secondary devices less than the control group. In the Indigo users group, the most bought source of energy was Indigo by topping up, 23 of 78 of respondents (29%) reported that they topped up the system in the week before the interview. Apart from Indigo, dry cell batteries were the most bought source of energy for lighting both for Indigo users and non-users - 27% and 43% of Indigo users and non-users respectively. While Indigo reduces reliance on some sources of lighting previously used, the indications are that these other devices are not fully eliminated. The majority of households using Indigo appear to be spending more on lighting than they did before acquiring the units. The enumerators attempted to collect information on amounts spent per household on lighting but this data proved difficult to obtain and levels of expenditure could not be reliably determined.

Those that combine Indigo with other devices had light for 263 minutes per day (181 minutes for Indigo plus 85 minutes for the other lighting devices) on the day prior to interview, that is 4 hours and 23 minutes of lighting, see Table 3. Households which only used Indigo and had no other source of light reported having 182 minutes of lighting (approx. 3 hours) on the day prior to interview. Results for both groups compare favourably with the control group which reported an average of 104 minutes (1 hour 44 minutes) of lighting, and with the baseline study which reported an average of 2 hours of lighting per day for all households.

"OUT OF 78 HOUSEHOLDS USING INDIGO, 17 (22%) ARE USING INDIGO ONLY, WHILE 61 (78%) USE OTHER DEVICES ALONGSIDE INDIGO."

Table 3. Mean minutes of lighting on the day prior to interview for Indigo users compared to the control group

CATEGORIES OF RESPONDENTS	N	MEAN TIME PER DAY OF INDIGO	MEAN TIME LIGHTING PER DAY OF OTHER DEVICES	THE TOTAL TIME FOR LIGHTING
1. TREATMENT GROUP				
Customers using Indigo only	17	182	0	182
Customers using Indigo as well as other devices	53	181	82	263
Customers who are not using the Indigo lantern but other devices only	8*	0	108	108
2. CONTROL GROUP	88	0	104	104

*The reason Indigo was not used on the day prior to interview is not known for certain but the most likely reason is that they were out of credit.

Survey respondents were asked about different uses of lighting in the household and the amount of time spent on each. "Family gathering" was the activity most commonly mentioned by both users and non-users of Indigo. This was followed by "reading for adults" and "studying for children". Table 4 shows the average time that households use light for these three activities. It also shows the share of Indigo in the lighting time for each activity. These different activities may take place simultaneously, making use of a shared lighting source. The results suggest that in households with Indigo which also use other devices there is significantly more time spent on all three activities, with the largest differences being on adults reading and children studying. The time for education/doing homework for children has almost doubled in the households that are combining Indigo with other lamps (128 minutes) compared with households just using Indigo (69 minutes), and is almost three times the study minutes for households not using Indigo (48 minutes). In the baseline study the average time children spent studying at home was reported to be 71 minutes. The survey asked about the overall amount of time children spent studying. The results suggest that there was an increase in total study time per day. This contradicts the findings of Grimm et al. (2015) mentioned earlier.

Table 4. Lighting time per day used by household for different activities (in minutes)

	TREATMENT GROUP				
ACTIVITIES	Type of lighting device	Customers using Indigo only	Customers using Indigo as well as other devices	Customers who are not using the Indigo lantern but other devices only	CONTROL GROUP
Time for Family gathering per day (lighting minutes)	N	11	53	8	61
	Indigo	93	99		
	Other devices		56	106	
	Total time	93	155	106	90
Time for Reading adult per day (minutes)	N	10	31	6	42
	Indigo	74	85		
	Other devices		80	28	
	Total time	74	165	28	66
Time for Study of children per day (minutes)	N	17	30	5	37
	Indigo	69	67		
	Other devices		61	47	
	Total time		128	47	48

As well as benefitting from more hours of light Indigo users also benefit from being able to charge phones at home, saving money and time, with less worry about phones being damaged or stolen. All households in the Indigo users group had at least one mobile phone while in the control group only 4% did not have one. The number of phones varies from one to four in the treatment group and from one to three in the control group. The study showed that 60% of Indigo users charged their mobile phones at home using Indigo, while 40% combined Indigo

"AS WELL AS BENEFITTING FROM MORE HOURS OF LIGHT, INDIGO USERS ALSO BENEFIT FROM BEING ABLE TO CHARGE PHONES AT HOME, SAVING MONEY AND TIME."

with external phone charging services. Indigo users and non-users that charge phones outside the home spent about the same amount of time, approximately 3 hours, to get their phone charged. This includes the charging time and travel. Both groups also reported paying a similar amount for charging a phone RWF 200 (approx. USD 0.26) a week. So a household with two phones and Indigo which charges those phones at home saves around RWF 400 (USD 0.52) a week on charging fees.

Households with Indigo use their phone as a lighting device more often than the control group, presumably because charging is easy and free. However, being able to charge phones at home seemed to make no significant difference to the amount of use made of the phone, except for their use as torches. Time spent calling, sending SMS, using mobile money and listening to the radio on the phone were similar for Indigo users and the control group.

Both Indigo users and non-users reported that they have experienced cases of headaches, respiratory problems, ocular problems and/or burns by kerosene in the 6 months before the interview. The number of households that reported that they suffered from these different sicknesses is higher in the group of non-users (66%) than in the users group (42%). Sixty-three percent (63%) of Indigo users against 32% of non-users reported that the quality of air is very good without specifying the reasons. The data suggests that Indigo users experience some health benefits as use of kerosene and candles is reduced.

3.3. SOCIO-ECONOMIC PROFILE OF INDIGO USERS

Based on the socio-economic data collected from the survey, which included age, education, occupation of head of the households, land size, house and other assets ownership, and monetary income of the households, a profile of the households owning Indigo products was created and compared to the national socio-economic classification of the population known as *Ubudehe* categorisation[2]. Households are placed in one of four categories based on their socio-economic status, and their property – in terms of land and other assets – and the occupation of the households' members. The categories and characteristics of Ubudehe have changed over time. The former classification consisted of 6 categories plus one for very rich people. In this classification categories 1 to 4 were considered as poor (extreme poverty, very poor, poor, resourceful poor) while 5 to 6 were considered as food and money rich. The current classification is made of 4 categories as follows:

- **Category 1:** Families who do not own a house and can hardly afford basic needs.
- **Category 2:** Those who have a dwelling of their own or are able to rent one but rarely get full time jobs.
- **Category 3:** Those who have a job and farmers who go beyond subsistence farming to produce a surplus which can be sold. The latter also includes those with small and medium enterprises who can provide employment to dozens of people.
- **Category 4:** Those who own large-scale business, individuals working with international organizations and industries, as well as public servants.

Updated figures for these new categories of *Ubudehe* classification are not yet available: the related national data collection is currently going on countrywide. However, based on the characteristics of new and old categories, the two first categories of the current classification seem to cover the old categories 1-4, while categories 5 and 6 correspond to the new 3rd and 4th categories. The Integrated Household Living Conditions Survey known as EICV4 shows that people considered as poor in 2013/14 were 39.1% and this could be considered as the equivalent of the current categories 1 and 2 of *Ubudehe*.

The households that acquired Indigo have an average size of 6 permanent members which is larger than the national average of household size which is 4.3[3]. Households using Indigo are mainly headed by men (76%) and the average age of the head of households is 47 years. Indigo customers are living on agriculture and earn an estimated monthly monetary income of RWF 36,000 (approx. USD 50). A large part of their income comes from selling plant products (56% of cases) and animal products (53%). Among Indigo customers, 67 households (86%) have some type of animal/livestock while 14% do not. This is much higher than the national situation where households with any type of livestock are estimated to be 32%[4] of the total. This means that Indigo users that own any type of livestock are more than twice the national average.

Almost all Indigo customers are living in their own house. The data shows that Indigo customers (87.2%) have houses covered by an iron sheet while 11.5% of them have houses with a tile roof. This is well above the standard for the average house based on the information provided by the EICV4. This report says that 61.1% and 0.4% of the local population have houses respectively roofed with iron or clay tile[5]. A big difference between the national situation and the Indigo customers has also been found on the type of floor of the house: 62% of Indigo customers have cemented floor while the national average of households with cemented houses in rural area is 21.1%.

Considering the characteristics of *Ubudehe* categories (2014-2015) and the profile of Indigo customers, most Indigo users could be classified under category 3. This is motivated firstly by the fact that 99% of Indigo customers own a house roofed with iron sheet or

2 http://www.gov.rw/news_detail/?tx_ttnews%5Btt_news%5D=1054&cHash=a315a8b0054e76f9c699f05ce24d3eb8 and/or http://loda.gov.rw/single/article/revised-categories-of-ubudehe-officially-launched/

3 NISR (2012), Rwanda population and housing census (2012)

4 NISR (2012), EICV IV: Enquête Intégrale sur les Conditions de Vie des Ménages (Integrated Households Living Conditions Survey)

5 The roof covered by the iron sheet is considered to be more expensive than the ones of local manufactured tiles

tiles, and with a cemented floor. Secondly, the Indigo users produce agricultural surpluses which they can sell. The survey found that 56% and 53% are selling respectively plant and animal products and have an average monthly income of RWF 36,000 (USD 50).

It is clear that Indigo users are not from the poorest sections of the population. This suggests that at least 39.1%[6] of Rwandan households, which are living under the poverty line, are unlikely to be able to afford Indigo. In addition, 24% of Indigo users said a monthly payment which is above RWF 3,000 is a challenge for them (the current fee is RWF 3,500 per month). There were also 32% that reported that they have been out of credit at least once because they were lacking the money to top-up the system. Even at the current low price a significant number of Indigo customers find it difficult to top-up their system because they don't have enough money. This is consistent with the baseline study finding where only 33% of rural households said they could afford RWF 1,000 a week for a product like Indigo.

6 NISR (2012), EICV IV: Enquête Intégrale sur les Conditions de Vie des Ménages (Integrated Households Living Conditions Survey)

This raises significant issues for policy makers who see solar home systems as a potential means to provide basic electricity for all off-grid households. More households could be reached by reducing the top up fee and extending the repayment period, but this would require businesses distributing systems to have access to additional working capital. Over time as the customer base grows scale efficiencies should also help lower costs, and the cost of components such as solar panels is also expected to fall. Even with reduced fees, however, many households will be unable to afford the product. Targeted subsidies for the poorest households might be considered but could be complex to manage and risk undermining the market. Cheaper, more basic products such as solar lanterns might be promoted as an alternative solution for poorer households, many of which do not own phones.

CONCLUSION

The project faced a number of challenges with the payment methods, with the local distributor's capacity, with changing tax regulations, and to a lesser degree with the technical performance of the product. Some of these issues were overcome during the project, while others remain lessons for future projects. Azuri continues to work with the local distributor and expects to complete deployment of the 10,000 units funded by the project around mid-2016.

Households which acquired Indigo reported clear benefits from using the product, though in the majority of cases it did not fully replace other devices, but rather allowed for additional lighting or phone charging. Households that adopted Indigo as their sole source of lighting or in combination with others had respectively 1.75 and 2.5 times more lighting time per day than the control group. This allowed Indigo users to find extra time for family gathering, education of children and reading for adults.

It proved difficult to establish the real amount spent per week by Indigo users and non-users on lighting, but it seems that the Indigo users pay more than the control group of non-users for lighting purposes. This is explained by the fact that many of the households that are using Indigo continue to use and buy other sources of lighting fuel.

Sixty percent of the households which own Indigo products charge all their phones at home and have seen the amount paid per week for charging disappear. This may offset spending on lighting. This leaves 40% of Indigo users that are charging phones out of the house, and spend money and time for charging. Households with Indigo appear to make much more use of phones as torches, perhaps because of the ease of charging them.

Seventy-six percent of Indigo customers said a monthly payment of RWF 3,000 would be convenient for them (slightly less than the current RWF 3,500 per month). Thirty-two percent of customers had been out of credit at least once because they did not have money to pay for the top up.

The Indigo customers can be mainly classified as category 3 of Ubudehe, i.e. the better off households in rural areas. It appears that the poorer sections of the Rwandan population are likely to find it difficult to pay for Indigo. This raises important issues about affordability and access to electricity in rural areas. Costs are likely to fall over time but other solutions, such as solar lanterns, may be a more appropriate option for the poorest households in the short-term. Issues of affordability can only ultimately be addressed through economic growth and increased household incomes.

REFERENCES

Bensch, G., Kluve, J. and Peters, J. (2010), Rural electrification in Rwanda – an impact assessment using matching techniques. *Ruhr Economic Papers*, No. 231, Ruhr-Universität Bochum (RUB), Department of Economics, Bochum, Germany.

Djamin, M., Lubis, A. Y., Alyuswar, F. and Nieuwenhout, F. D.J. (2002), Social impact of solar home system implementation: the case study of Indonesia (Kolaka, south east Sulawesi), World Renewable Energy Congress VII, 2002.

Grimm, M., Munyehirwe, A., Peters, J. and Sievert, M. (2015), A first step up the energy ladder? Low cost solar kits and household's welfare in rural Rwanda. *Ruhr Economic Papers*, No. 554, Ruhr-Universität Bochum (RUB), Department of Economics, Bochum, Germany.

Gustavsson, M. and Ellegård, A. (2004), The impact of solar home systems on rural livelihoods. Experiences from the Nyimba Energy Service Company in Zambia, *Renewable Energy*, Volume 29, Issue 7, pages 1059–1072.

Jacobson, A. (2007), Connective Power: Solar Electrification and Social Change in Kenya, *World Development*, Volume 35, Issue 1, pages 144–162.

Khan, S. A. and Azad, A. K. M. A. M. (2014), Social impact of solar home system in rural Bangladesh: a case study of rural zone, *IAFOR Journal of Sustainability, Energy and the Environment*, Volume 1, Issue 1, pages 5-22.

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