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Demand for off-grid solar electricity – Experimental evidence from Rwanda

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Abstract

Providing electricity to the unconnected 1.1 billion people in developing countries is one of the top political priorities of the international community, yet the costs of reaching this objective are very high. The present paper examines whether the objective and the associated costs are justified by the value that target beneficiaries assign to electricity. We provide experimental evidence on the revealed willingness-to-pay (WTP) for three types of off-grid solar electricity devices. Our findings show that households are willing to dedicate a substantial part of their expenditures to electricity. In absolute terms, though, the WTP does not suffice to reach cost-covering prices. Different payment schemes, which we randomized across our sample, do not alter the WTP significantly. If universal electricity access is to be achieved, direct subsidies might be necessary. We argue that from a public policy perspective it is more rationale to promote off-grid solar than grid-based electrification because of its better cost-benefit performance.

Keywords: Technology adoption, electrification, willingness-to-pay, real-purchase offer game, energy access

JEL codes: D12, O12, O13, Q28, Q41.

1. Introduction

Universal electricity access is a primary goal of the international community. The Sustainable Development Goals (SDG) and the United Nations' initiative 'Sustainable Energy for all' (SE4All) call for connecting the 1.1 billion hitherto non-electrified people worldwide by 2030. Yet, the contribution of electricity to economic development is unclear. It is beyond discussion that the economic transition in nowadays industrialized countries would not have been possible without electrification. However, the right timing of electrification in developing countries is under open debate given high investment-costs and modest short-term impacts. For Asian and Latin American countries Lipscomb et al. (2013), Rud (2012), van de Walle et al. (2016), and Khandker et al. (2013) find positive effects on various socio-economic outcomes. For Africa, in contrast, it is less clear whether electrification triggers massive economic development (Dinkelman 2011, Lenz et al. 2017, Peters and Sievert 2016). At the same time, the costs of electrification are substantial. OECD/IEA estimates that for Africa alone the investment requirements to achieve universal access by 2030 are at 19 billion USD annually, which corresponds to almost 45% of the yearly official development assistance influx to the continent (IEA 2011, World Development Indicators 2014).

Only recently, researchers have started questioning whether public funds should be used to subsidize mass electrification. Especially in developing countries the tight governmental budgets are up against various underfinanced public services and thus opportunity costs are high. Most prominently, this case is made by Lee et al. (2016) who randomize different connection fees across villages in Western Kenya to obtain households' revealed Willingness-to-Pay (WTP) for grid access. Since the WTP they observe only covers a small part of the required costs, they suggest that electrification creates a ’welfare loss´ ranging between 510 and 1,100 USD per household. While Lee et al. acknowledge that a revealed WTP is constrained, for example by limited access to credit, and also only reflects internalized benefits, they argue that non-internalized private and social benefits are unlikely to justify subsidies in this order of magnitude.

In the present paper, we complement Lee et al. (2016) by studying the revealed WTP for three different off-grid solar technologies. Investment costs of these devices vary between 13 and 180 USD, compared to at least 1,000 USD per connection if the grid is extended. The cost-structure of on-grid electrification is much more complex and case-specific because of the required large-scale infrastructure including power plants, transmission and distribution lines as well as the household connection. The distance to the existing grid and the population density play decisive roles. Cost considerations for off-grid solar are therefore much less sensitive to the underlying assumptions. At the same time, service levels are obviously lower for off-grid than for grid connections. The solar kits used in this paper allow for different energy usage levels ranging from just one task light to several lighting sources, telephone charging, and radio usage. Unlike access to grid electricity, solar off-grid does not allow for high-wattage appliances like machinery, electric stoves, fridges, or irons. Thereby, while Lee et al. (2016) provide novel insights on the cost-effectiveness of electrification at the upper bound of the technological spectrum, the present paper is the first to study cost-effectiveness at the lower bound.

Using a sample of 325 households, randomly selected in 16 rural communities spread across rural Rwanda, we elicit the WTP using a Becker-DeGroot-Marschak real-purchase offer bidding game. Each household was offered individually three different types of off-grid solar, a 0.5 Watt, a 3.3 Watt, and a 20 Watt device. We find that the average WTP for the three solar kits is between 38 and 55 percent of their market prices. Also at the upper tail of the distribution, only few households are able and willing to pay amounts that come close to the market prices. If we take the perspective of Lee et al. (2016) and weigh up the consumer surplus from electrifying rural households and the costs of providing it, our findings suggest that electrification via off-grid solar technologies still generates social costs between 8 and 83 USD per connection. This is considerably lower than the 'welfare loss' that Lee et al. (2016) observe for on-grid electrification. Although in absolute terms external effects of off-grid solar are probably much lower than for on-grid electricity, from a cost-benefit perspective off-grid solar seems to be more worthwhile, especially in poor remote areas. If the focus is on short-term development goals, the benefits of off-grid solar might well be high enough to justify subsidies that close the gap between the market price and the price households are able to pay (see Grimm et al. 2016 and Samad et al. 2013).

This welfare oriented cost-benefit analysis that is also pursued in Lee et al. (2016) assumes that public funds are used to provide access to electricity. Yet, the United Nations' SE4All initiative takes a different stand and plans to distribute off-grid electricity without end-user subsidies through the private market (see Lighting Global 2016). Our findings suggest that this strategy will not be successful in reaching the poorer populations in rural Africa. The vast majority of them will not be able to pay cost-covering prices. This observation is in line with the broader literature on the adoption of new socially desirable technologies. In recent years, many studies have shown, in particular for health relevant products, that demand is highly price elastic (see Cohen and Dupas 2010, Dupas 2014, Tarozzi et al. 2014, Kremer and Miguel 2007, Mobarak et al. 2012). The similarity between these technologies and electricity is that benefits are not internalized and policy therefore intervenes to facilitate adoption. This branch of literature strongly advocates in favor of 'cost-sharing' dissemination strategies, i.e. subsidized end-user prices to bring adoption rates to a socially desirable level (Bates et al. 2012).

Also among policy makers affordability problems of the poor are of course well-known. The hypothesis is typically that people would be willing to pay cost-covering prices, but in reality are constrained by a lacking liquidity to shift consumption between today and the future. Hence, relaxing financial constraints via consumer loans or payment-over-time are preferred strategies of World Bank's Lighting Global platform, the flagship program for off-grid solar energy (Lighting Global 2016). To test whether this can indeed be a promising route to universal access, we randomized three different payment periods across our sample (one week, six weeks, and five months). We thereby also contribute to the literature on liquidity constraints and technology adoption in poor settings. This has been studied by Beltramo et al. (2015) for improved cookstoves in Uganda, by BenYishay et al. (2016) for hygienic latrines in Cambodia, by Devoto et al. (2012) for piped water access in Morocco, and Tarozzi et al. (2014) for malaria bednets in India. Yoon et al. (2016) test the effect of a one week delayed payment period on the revealed WTP for a solar lantern in India. Our paper is thus also the first to study the effect of variations in payment periods on the real-world WTP for different off-grid solar technologies.

We find that relaxing the liquidity constraint does not increase the WTP substantially. An extension of the payment period from 7 days to 5 months increases the WTP for all three kits by 8 to 13 percent. This is most probably not enough to cover capital costs and overheads that would be associated with a credit based financing scheme (reflected in its interest rate). An extension of the payment period from 1 week to 6 weeks does not increase the WTP at all. This indicates that even much longer payment periods might only help certain parts of the population to finance their own electrification. Cash-flow incomes and replaceable baseline energy expenditures are simply too low to make the investment affordable (see also Bensch et al. 2016). If a more rapid uptake of solar technologies is desired, end-user subsidies must be considered.

The remainder of the paper is structured as follows. In Section 2 we shortly discuss the energy policy and country background, Section 3 describes our methodological approach and our data. In Section 4 we present our main results on the WTP and the impacts of the payment periods. Section 5 briefly considers a simple cost-benefit analysis for the three kits and the payment behavior of the participants. In Section 6, we interpret the results in the light of the policy agenda and highlight limitations.

2. Background

2.1. Policy background

The United Nation's Sustainable Energy for All (SE4All) initiative was launched in 2011 and has called on governments, donor organizations, and the private sector to provide those 1.1 billion people with electricity by 2030 that are still deprived of access. For most African governments, grid extension is the most obvious intervention to increase the access to electricity. However, in recent years, decentralized solar technologies have gained importance as a lower-cost alternative, in particular because production costs of panels, storage systems, and LEDs have decreased considerably. Since 2009, the World Bank program 'Lighting Global' supports the international off-grid lighting market for products of up to 10 Watts. The promoted so-called pico-solar products provide different basic energy services depending on the panel size, such as lighting or radio, and mobile phone charging. Larger off-grid solar products, typically referred to as solar home systems (SHS), are also able to run TV sets and comparable devices, but no high-wattage devices (e.g. fridges) and appliances running on alternate current.

In the absence of electricity, people in rural Sub-Saharan Africa light their homes using traditional lighting sources – kerosene driven wick and hurricane lamps or candles. Additionally, dry-cell battery driven LED-lamps have become available in recent years in almost every rural shop and are increasingly used (see Bensch et al. 2015). Some households in rural areas even only resort to the lighting that the cooking fire emits. For many households, expenditures on kerosene and batteries constitute a considerable part of their total expenditures. This level of baseline lighting consumption is an important factor affecting the decision to invest into a solar kit, since it determines the replaceable expenditures and thus the cash flow expectations.

In principle, Lighting Global's approach assumes that off-grid solar products will make their way into households through the market. The program has introduced a quality verification system and supports manufacturers and retailers in overcoming information asymmetries that might prevent customers from buying the products. Credit constraints are supposed to be eased via credit and smart payment systems such as the Pay-as-you-go mechanism (PAYG), which allows the customers paying for the kit in small installments via mobile money. An additional innovative feature that can be combined with PAYG is to lock the device in case of non-payment through an installed microchip connected to the mobile phone network. Generally, Lighting Global opposes direct end-user subsidies. According to Lighting Global (2016), around 4.3 million pico-solar kits were sold in Africa, with sales concentrating in Ethiopia, Kenya, and Tanzania. Customers so far are mostly somewhat better-off households. In the present paper, we test whether the market can be expanded to remote and poorer areas. It is important to emphasize that next to the branded and quality verified products promoted by Lighting Global also non-quality verified, i.e. non-branded, solar products are available virtually everywhere in rural Africa (see Bensch et al. 2016 and Grimm and Peters 2016).

The link between Lighting Global and SE4All is established by the Global Tracking Framework and its multi-tier system (SE4All 2013), which defines what type of electricity supply qualifies as modern energy. For example, a regular connection to the national grid qualifies as Tier 3, because it allows for using lighting, a television, and a fan all-day. An SHS would qualify for Tier 1 or 2 depending on its capacity. Tier 1 requires having access to a peak capacity of at least 1 Watt and basic energy services comprising a task light and a charger for radios or phones for four hours per day. Most solar products promoted by Lighting Global as well as two of the three kits used in this study qualify for Tier 1. Our smallest kit is just a tad below the Tier 1 threshold (because it only includes a lamp and lacks a phone charger, see Section 3.1). There is a wide spread between the service qualities of the different tiers, which is also reflected in the required investment costs: the retail price of the smallest pico-solar kit used in this study is at around 13 USD. For comparison, World Bank (2009) estimates a cost range for on-grid electrification in rural areas of 730 to 1450 USD per connection, which is confirmed by Lee et al. (2016) for the case of Kenya and Lenz et al. (2017) for Rwanda.

2.2. Country Background

The Government of Rwanda sees electrification as a priority to reach its poverty reduction goals (see MININFRA 2016). Rwanda's energy sector is undergoing an extensive transition, in which electricity provision plays a dominating role. It is the government's objective to increase the electrification rate to 70 percent of the population by 2017/2018 and to full coverage by 2020. The key policy instrument is the huge Electricity Access Roll-Out Program (EARP) that increased the national connection rate from 6 to 24 percent country wide between 2009 and 2015. While EARP Phase I relied on grid electrification only, Phase II provides half of the connections via decentralized technologies (SE4All 2014), including SHS and pico-solar kits (MININFRA 2016). More recently, the so-called Bye Bye Agatadowa initiative has attracted some attention, which aims at eliminating kerosene lamps completely from the country. In the African context this engagement of the government is extraordinary. The communities sampled for this study are not yet reached by these activities and no electricity related roll-out is foreseen for the future. They hence resemble to typical off-grid areas in Africa.

3. Research approach and data

We conducted a Randomized Controlled Trial (RCT) among 325 randomly selected households in 16 rural communities in Rwanda and elicited the WTP for three different solar kits using a real-purchase offer game based on the Becker-DeGroot-Marschak (BDM) mechanism. Each household was visited individually and was randomly assigned a payment period of either one week, six weeks, or five months. The randomization was stratified on the community level. In this section, we first briefly describe the three offered solar technologies, followed by the sampling process, and the bidding game to elicit the WTP.

3.1. Off-grid technologies offered in bidding game

Table 1 presents the three types of solar electricity devices we offered to the participants in our experiment. The most basic kit is the d.light S2 (“Kit 1” in the following), an LED lamp with an integrated small solar panel. It only provides lighting and thus does not reach Tier 1 in the SE4ALL multi-tier metric. The second offered kit is Sun King Pro 2 (“Kit 2”) and since it provides lighting and phone or radio charging via two USB ports it is borderline eligible for Tier 1. Kit 1 and 2 are portable and can be used as a desk lamp or attached to a wall or the ceiling. The third kit offered, the ASE 20W Solar DC Lighting Kit (“Kit 3”), is a SHS, i.e. the solar panel is installed outside and charges a separate battery, which in turn is connected to four LED lamps and a charging station with six USB ports. Kit 3 also corresponds to a Tier 1 device as it provides a peak capacity of 20 W, but in terms of the variety of electricity services it comes close to Tier 2. Market prices of the three kits vary considerably between 13 USD for Kit 1 and 180 USD for Kit 3.

Table 1: Specifications of solar technologies

	Kit 1	**Kit 2**	**Kit 3**
			
Model	d.light Design S 2	Greenlight Planet Inc. Sun King Pro 2	ASE 20W Solar DC Lighting Kit
Full battery run time[1] (in hours)	6.5	5.9 - 13.1[2]	4 – 36[3]
Total light output per kit (in lumen)	25	81 – 160[2]	220
Panel size (in Watt)	0.5	3.3	20
Features	1 LED lamp	1 LED lamp, 2 USB ports, 3 brightness settings	4 LED lamps, 6 USB ports, Separate battery of 14Ah
SE4ALL multi-tier classification	Tier 0	Tier 1	Tier 1
Approximate market price in Rwanda	13 USD (10,000 FRW)	37 USD (29,000 FRW)	180 USD (140,000 FRW)

[1]run time estimates do not include mobile phone charging; [2]depending on the brightness setting; [3]depending on the number of lamps in use. Sources: https://www.lightingglobal.org, Dassy Enterprise Rwanda; Pictures: Brian Safari, IB&C.

3.2. Sampling

The survey population was sampled on two levels, communities and households. First, survey communities were selected in a way that they resemble typical target regions of solar technologies, not only in Rwanda but also beyond. We used four selection criteria:

(i) Communities are not foreseen or expected to be grid-connected in the near future. This would obviously influence the WTP.

(ii) Areas exhibit appropriate solar radiation levels that are also typical for Rwanda and other African countries (see Figure 1).

(iii) Communities are not exposed to systematic marketing activities of solar product companies. The closest selling points are in towns nearby and hence are quite difficult to access. Easy access to selling points would create preconceived price ideas, which could distort the bids in the real-purchase offer game. In addition, this reduces the risk of strategic bids between their reservation price and the market price to resell the kit for a profit.

(iv) Communities are not adjacent. Communication between survey participants could influence the WTP.

An assessment of all criteria was obtained from the Rwandan government and local authorities on the cells level before we went to the field. Effectively, these criteria resulted in a selection of relatively remote communities, which, as we argue, are the ultimate target regions for small-scale decentralized electricity sources, also in other African countries. We surveyed 16 communities in 11 different sectors, spreading over three out of five Rwandan provinces (see Figure 1). In a second step, 325 households, equally distributed across the 16 communities, were chosen through simple random sampling on the community level at the day of the field visits. Households could not self-select into participation.

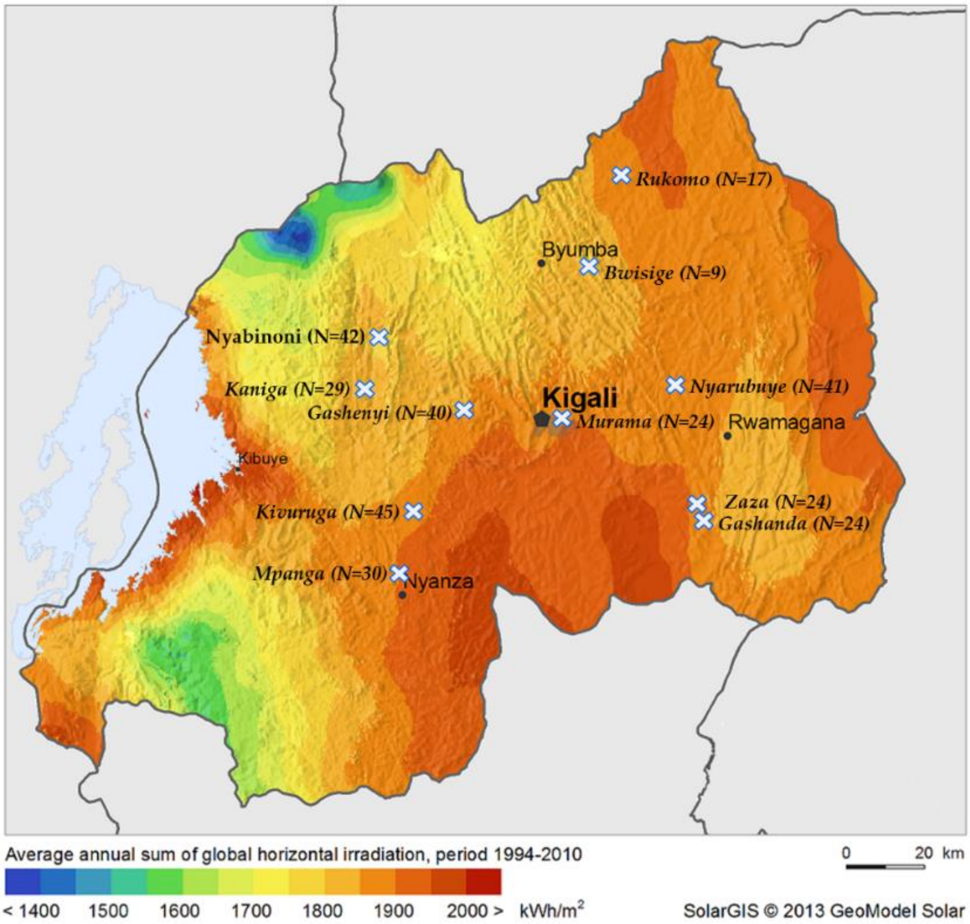

Figure 1: Sectors surveyed and global horizontal irradiation levels

Note: Crosses indicate the sectors surveyed, the sample size surveyed per sector is in parentheses.
Source: Own illustration based on SolarGIS Solar Radiation Map for Rwanda.

3.3. Survey implementation and the real-purchase offer game

The survey was implemented between August and November 2015 in cooperation with Inclusive Business and Consultancy (IB&C), a Kigali based consultancy, Rwanda Energy Group (REG), Rwanda's public energy agency, and Dassy Enterprise, a Kigali based Rwandan company that markets branded solar products.

In 14 of the 16 communities, we conducted interviews with the community chief in order to elicit basic information on living conditions and the existence of social infrastructure. For the household interviews, the financial decision maker was called and informed that we would sell a solar kit, but following a sales procedure different from what is usually known from the market. All sampled households were asked for their consent to be interviewed and to participate in the bidding game, but were not informed about the research purpose or the experimental character of the study, i.e. the randomization of the payment periods. Hence, typical survey effects might occur, but Hawthorne effects are unlikely. Enumerators worked in parallel within one community to avoid communication between participating households. Figure 2 presents the participant flow and the survey implementation.

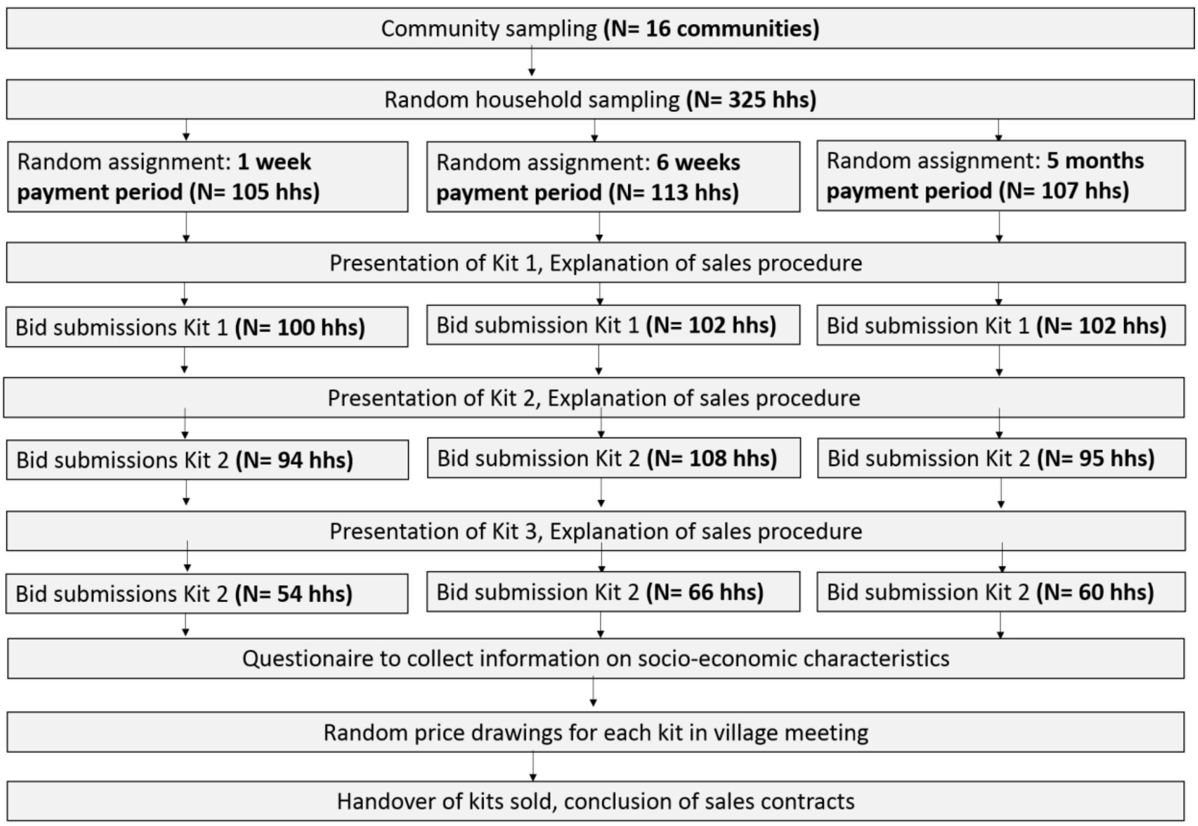

Figure 2: Participant Flow

The enumerator presented the solar kits in a consecutive way to the household, i.e. when Kit 1 was offered the household was not aware of the offers for Kit 2 and 3. The enumerators had been trained beforehand by our solar kit provider Dassy Enterprise to convey the key product information. Kit 1 and Kit 2 were demonstrated during the interview, while Kit 3 was too heavy to be taken to each household and was therefore only described in all details. Then, enumerators explained the BDM real purchase offer procedure. The interviewed household were offered the solar kits and told that the price for each kit would be drawn randomly in public in the afternoon. It was emphasized that the price was neither negotiable nor in whatever manner influenceable by the enumerator or the household. The randomly assigned payment period (one week, six weeks or five months) was announced and the respondents were asked for the highest price they would be willing and able to pay. At the same time, respondents were instructed that only if their bid exceeded or equaled the randomly drawn price, they could purchase the product. The price to be paid was the randomly selected price, not the stated one. Moreover, it was explained that if the bid felt below the randomly selected price, the household would not be able to purchase the product. Adapting the bid afterwards was thus not possible.

We opted for the BDM approach since unlike stated WTP approaches it incentivizes truthful responses. If the bidder overstated her real reservation price, she would have to buy the product at a price higher than her actual valuation. In contrast, by understating her real reservation price she might miss a purchase opportunity at a price that is less or equal to her valuation. Another useful feature of BDM is that it allows separating bids from market price and thereby yields more precise, higher-resolution data on households' WTP as compared to take-it-or-leave-it approaches, which provide only WTP bounds[1].

The main criticism brought forward against the BDM method is its complexity. In particular, in poor rural settings the respondents' comprehension can be a bottleneck. Therefore, before we offered the solar kits, we conducted a hypothetical practice round for a different and well-known product (a mobile phone), without real purchase. In general, the game was well understood.

The three kits were presented and offered separately, starting with Kit 1 and ending with Kit 3. Before the respective next kit was offered, the participants had to decide which product they would buy in case that two of the submitted bids exceeded the drawn prices. This ensures independency of the different bids.

The instructions the enumerators presented to the participants before the game contained some light marketing messages (see Appendix A). The key features of the three kits were introduced, including the different electricity services they would allow for (see Section 3.1). Participating households were informed about average spending of rural Rwandan households on batteries, kerosene, and candles, i.e. those sources that can be replaced by the solar kit, using the information we collected during earlier surveys (see Lenz et al. 2017). A one-year warranty by Dassy Enterprise's in-the-field services was granted.

Moreover, the participant was informed about the minimum and maximum prices in the draw. The lower bounds of these ranges were set at a very low price level of approximately 30 percent of the market prices for Kit 1 and Kit 2 and at 65 percent of the Kit 3 market price[2]. The upper price bound was the Rwandan market prices of the respective solar kit. We

[1] See Berry et al. (2015) for a profound discussion of BDM.

[2] The price range was between 4 USD and 13 USD for Kit 1, 13 USD and 38 USD for Kit 2, and between 115 USD and 190 USD for Kit 3.

chose this upper bound to be sufficiently high to cover the participants' maximum WTP (which turned out to be true). The price range was disclosed to the participant in order to facilitate the game. Answering a non-anchored WTP question can be cognitively very challenging (Kaas et. al 2006), particularly when participants are confronted with an unknown product. Based on preparatory field visits our expectation was that respondents know too little about the effective prices and hence an entirely non-anchored WTP would have even discouraged participation. Note that the participant was not prevented from bidding outside the range.

The random price draw for each solar kit was done openly in an afternoon community meeting in the presence of all participants after the household visits were completed. We decided to draw prices on the community level (i.e. one price per kit and community) instead of the household level, in order to avoid social tensions induced by different prices within the same community.

Those participants whose bids exceeded the drawn price received the product the same day and signed a binding sales contract. They were offered the possibility to make a voluntary advance payment. Remaining payments could be made via mobile banking through one of the three Rwandan mobile phone operators. All but two households were sufficiently familiar with mobile banking services. These two households opted out of the game already during the interview.

4. Results

4.1. Summary statistics and balancing test

The average community size is at 178 households and 847 people. The communities are quite remote, located on average at a 14 km distance from the next main road, which for mountainous Rwanda is considerable. Public infrastructure such as primary schools, health centers, and weekly markets is only available in a few communities. Only two of the 14 interviewed community chiefs expect their community to be connected to the national electricity grid in the near future. In line with our selection criteria, communities are not exposed to systematic promotion of solar products. Pico-solar products comparable to our Kit 1 and Kit 2 are not available at all. Only around half of the communities had some exposure to NGO-led marketing activities of larger SHS similar to our Kit 3. As a consequence, adoption rates of solar products before the study were relatively low even if the technology is not completely new to the population. Only around 13 percent of our sample, i.e. 41 households, already possessed a solar kit. The majority of these households (63 percent) received their kit from urban areas, presumably from friends or relatives. The remaining households mostly received them directly from an NGO. In order to test if respondents have preconceived price information we asked them to predict the prices of our three kits before the BDM game. This variable actually suggests that most of the solar kit owning households have received them for free because only 11 out of the 41 households stated to know the price of solar kits but turned out to be unable to make a prediction that came close to the real price. Among those 88 percent that do not yet possess a solar kit, only 10 respondents say they have an idea about the market prices of the three kits offered by us, but again none of them was actually able to name a value close to the real price. These insights suggest that information about solar kit prices is very limited in the surveyed communities.

We must assume that the WTP expressed by solar-kit-owning households in the bidding game convey a different message than those expressed by households without a kit, because they would obviously bid for a second modern lighting source. The same might apply to households that already own a rechargeable lamp or a car battery. We therefore control for these electricity sources in our assessment later in this section[3].

Table 2 also summarizes the key socio-economic characteristics of our sample and tests whether the randomized payment period groups are balanced. The multiple t-tests show that the groups do not differ significantly. For those variables that do exhibit statistically significant differences the magnitude of the difference is small. We will nonetheless control

[3] As a robustness check we redo the WTP analysis for a restricted sample for which we exclude households that already own a solar kit or a car battery. Results can be found in the Appendix B Table B.2. It shows that the results in the following sections are robust to the exclusion of these households.

for all the variables in the subsequent evaluation of the randomized payment schemes. The average household size is about five members and total monthly expenditures (excluding energy expenditures) sum up to 58 USD on average. About 30 percent of all household members are children enrolled in school, which is noteworthy because they are potentially frequent users of lighting devices.

Table 2: Descriptive statistics and balancing test

	Mean full sample	*p*-value Period 1 vs. Period 2	*p*-value Period 1 vs. Period 3	*p*-value Period 2 vs. Period 3
Socio-economic characteristics				
Female respondent/bidder	0.42	0.472	0.829	0.347
Head of HH years of education	4.44	0.439	0.399	0.117
HH size	4.53	0.118	0.640	0.038*
Head of HH is a farmer	0.80	0.780	0.471	0.650
Share of students in HH	0.30	0.013*	0.632	0.037*
House with tile roofing	0.21	0.769	0.220	0.340
Monthly non-energy expenditures (USD) [1]	57.68	0.025*	0.081*	0.821
Baseline energy consumption				
Monthly phone charging expenditures (USD)[1]	1.11	0.634	0.409	0.664
Monthly energy expenditures (USD)[1,2]	8.71	0.059*	0.252	0.348
Owns rechargeable lamp	0.08	0.680	0.486	0.262
Owns car battery	0.02	0.052*	0.083*	0.767
Owns solar kit	0.13	0.238	0.845	0.324
N	324	218	211	219

Note: *** p<0.01, ** p<0.05, * p<0.1 denote statistical significance. [1] The values are bottom and top coded at 2% and 98% of the distribution respectively to eliminate outliers. [2] Including expenditures on kerosene, dry-cell batteries, and candles; we excluded expenditures for charcoal and firewood since services these fuels are used for (cooking, ironing) are not replaceable by solar kits; for those 26 households who own a rechargeable lamp we did not elicit expenditures for recharging the lamp.

Baseline energy consumption is dominated by lighting expenditures for candles, kerosene, and dry-cell batteries as well as expenditures for dry-cell batteries for radio usage. About one USD per month is spent on average on mobile phone charging, which is typically done at charging stations operated for example by hair dressers or other shops, which are available in most communities. Likewise, car batteries and rechargeable lamps are charged in such shops or in the next electrified community. Total monthly energy expenditures that can be considered to be replaceable by solar kits – this excludes expenditures for cooking and charcoal ironing – amount to 10 USD on average or around 13 percent of total household expenditures.

To get a sense of cost effectiveness, we calculate the theoretical amortization period of the solar products offered in our experiment. The total energy expenditures that can be replaced are obviously an important assumption in this calculation. Since especially the smaller kits will not replace these costs completely, we introduce a 'replacement factor' that approximates the share of expenditures in kerosene, dry-cell batteries, and candles to be effectively replaced. We assume Kit 1 and 2 to replace approximately 75 percent and Kit 3 to replace all lighting expenditures (see Table 3)[4]. Kit 2 and Kit 3 furthermore replace all mobile phone charging costs. Table 3 shows, the resulting amortization periods of 15, 19, and 79 months for the three kits are quite considerable given the poor setting.

Table 3: Savings potential of solar kits

	Average replaceable energy expenditures in USD on…				Total monthly savings (in USD)	Amortization (in months)
	*…phone charging * RF*	*…candles * RF*	*…batteries for lighting * RF*	*…kerosene for lighting * RF*		
Kit 1	1.11 * 0.00	0.16 * 0.75	0.66 * 0.75	0.35* 0.75	0.88	15
Kit 2	1.11 * 1.00	0.16 * 0.75	0.66 * 0.75	0.35 * 0.75	1.99	19
Kit 3	1.11 * 1.00	0.16 * 1.00	0.66 * 1.00	0.35 * 1.00	2.28	79

Sources: Expenditures data from data set; replacement factors (RF) are derived from Grimm et al. 2016.

4.2. Revealed willingness to pay in bidding game

Virtually all visited households agreed to participate at least in one bidding game (see Table 4). In total, 164 households won the bidding game, i.e. their bid exceeded the randomly drawn price (66 for Kit 1, 88 for Kit 2 and 10 for Kit 3). Only ten of these winning households refused the purchase, either because they bid too high (four households) or after the price drawing desired a different kit than the one they successfully bid for (six households). Effectively, 154 households purchased a kit. As can be seen in Table 4, some households did not make a bid. The highest share of non-bidding is observed for Kit 3 (44 percent) and clearly below 10 percent for Kit 1 and 2. The dominating reason for non-bidding is that households decided that they are not willing or able to make a bid above the lower bound (remember that the range for the randomly determined prices was disclosed before the game). In order to avoid a potential bias because of this opting-out behavior we estimate a Tobit model to account for the censored sample.

The results of the bidding game can also be found in Table 4, without yet accounting for the different payment schemes. We show both the WTP of only those households that made a bid and the corrected WTP using the Tobit. It can be seen that these two estimates do not differ considerably. The average bid for Kit 1 across all treatment groups is at roughly 5 USD, which is equivalent to 38 percent of the market price. The price bid for Kit 2 is at slightly less

[4] See Grimm et al. (2016) for expenditure effects of solar kit usage.

than 17 USD, covering 45 percent of the market price. For Kit 3, the average bid is at 97 USD and thus 54 percent of the market price[5].

Table 4: Bidding game outcomes, full sample

	Kit 1	Kit 2	Kit 3
Respondent participates in bidding game	0.94	0.92	0.56
Bid amount, bidders only (USD)	4.92	16.84	93.84
	(2.06)	*(7.16)*	*(45.17)*
Bid amount full sample (USD, Tobit corrected)	4.90	16.66	96.88
	(2.01)	*(6.95)*	*(34.60)*
Market price (USD)	13	36	180
Bid as share of total monthly expenditures[1,2]	19.77	61.38	343.06
	(24.46)	*(61.38)*	*(605.64)*
Price drawn (USD)	7.44	22.68	154.60
N Sales in experiment	66	88	10
N contracts effectively signed	60	84	10
Number of observations	324	324	324

Note: Standard deviations in parentheses.[1] Values are bottom and top coded at 2% and 98% of the distribution respectively to eliminate the effect of outliers.[2] Excluding expenditures on wood and rechargeable lamps.

Figure 3 uses the households' WTP to illustrate the demand curves for the three kits. The figure reveals that hardly any participant submitted a bid that comes close to the market price, which is indicated by the upper price bound. Additionally, it shows that the end-user prices at which full uptake would take place in our sample amount to less than 10 percent of the kits' market prices, namely 1.3 USD for Kit 1, 3.9 USD for Kit 2, and 6.4 USD for Kit 3. The distribution of bids also suggests, though, that disclosing the price range to the bidders (the two dashes) might have induced an anchoring effect as the bids perceivably cumulate right above the lower price bound in all payment scenarios for Kit 1 and Kit 2. Two distortive effects could be at work: First, bids could be biased downwards because participants gamble to get the kit at the lower price despite the incentive compatibility of the game. Second, participants with a real WTP slightly below the lower bound might be tempted to submit a bid and adapt it to the lower bound. Even if we – conservatively – assume the estimates to be slightly biased downwards, it seems safe to conclude that the true willingness to pay for the vast majority of households is clearly below the market price. Only few observations reach this upper bound.

[5] The WTP for the restricted sample excluding those households that already possessed a solar kit or a car battery before our visit shows that our results are robust. The WTP are quite similar at 4.91 USD for Kit 1, 17.24 USD for Kit 2, and 94.51 USD for Kit 3.

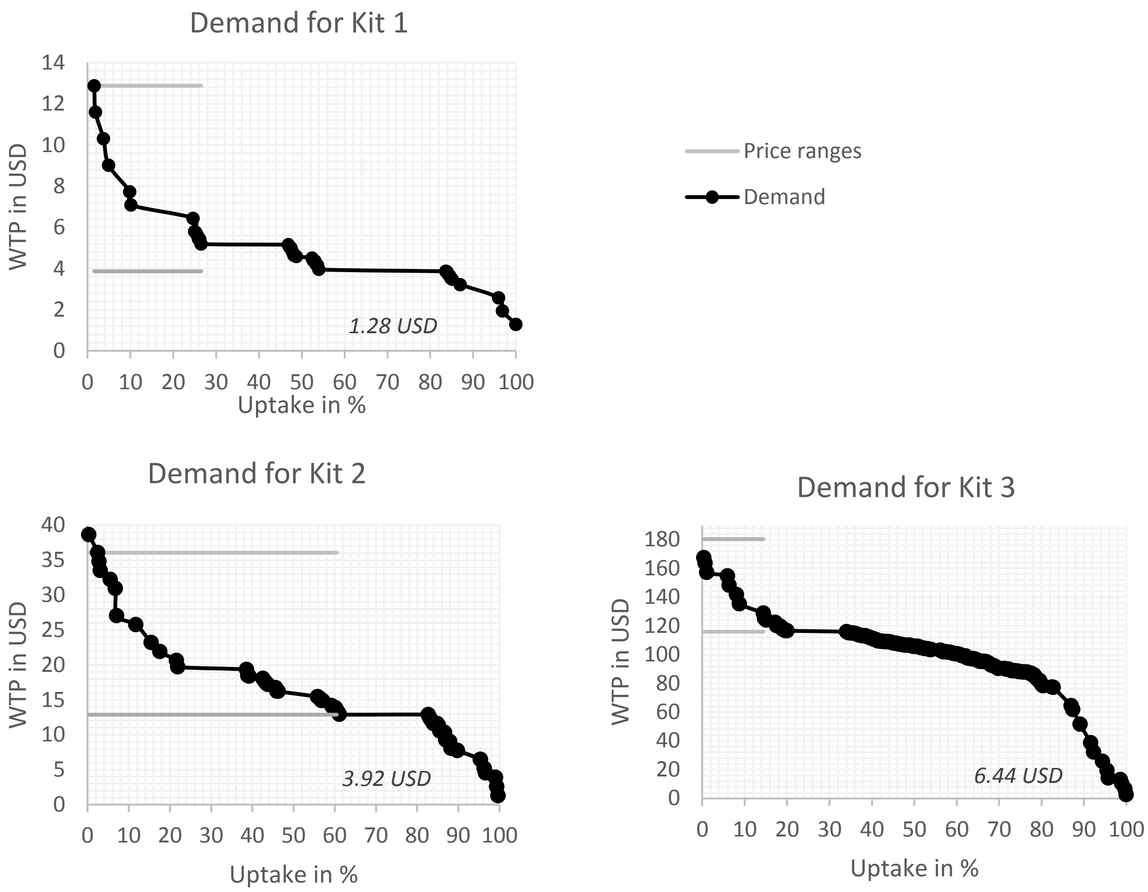

Figure 3: Demand for solar kits

Note: Price in italics refers to price that would lead to 100 percent uptake.

These average WTP levels have the following policy implications: Households in remote rural areas are only willing to pay prices that cover half of the current market prices at most. It is important to emphasize that this is clearly not due to a lack of interest, since comparing the bids to the households' total expenditures reveals the priority that modern lighting constitutes for people in rural areas (see Table 4). While already the WTP for Kit 1 corresponds to almost 20 percent of people's monthly expenditures, it is especially the increase of bids when phone charging services are added that is striking. For Kit 2, the average WTP corresponds to 61 percent of the total monthly expenditures. For Kit 3 the average bid even corresponds to 343 percent of the bidders' monthly expenditures. Qualitative statements in open interviews also confirmed the importance of electricity for households even if provided by off-grid solar and not the grid.

4.3. Effect of liquidity constraints

In this section, we examine the causal effect of liquidity constraints on the bidder's WTP. For each of the three solar kits we regress the bidder's WTP in a log-linear model on the randomized payment scheme and a set of socio-economic control variables. We again account for the censored samples by using a Tobit Model. For all three kits we include community-fixed effects and control for the date of the bidding game. The date might have an effect because the survey work was spread across three months and later interviews are closer to Rwanda's short harvest period in December that tends to relax households' tight cash constraint. Standard errors are clustered at the community level. The results are shown in Table 5. We subsequently include the two sets of control variables already presented in Table 2, i.e. socio-economic characteristics and baseline energy consumption variables. The latter might be endogenous to the reported WTP, but they could as well be important covariates leading to an omitted variable bias if not accounted for. As we will see, the results turn out to be robust, so both potential biases are probably negligible.

Table 5: Payment periods and willingness to pay

	Kit 1			Kit 2			Kit 3		
Payment periods									
Payment period: 6 weeks	0.012	0.021	0.023	0.049	0.044	0.056	0.060	0.065	0.058
	(0.801)	(0.633)	(0.627)	(0.333)	(0.367)	(0.256)	(0.240)	(0.203)	(0.245)
Payment period: 5 months	0.119	0.106	0.111	0.086	0.076	0.073	0.085	0.067	0.080
	(0.011)**	(0.037)**	(0.017)**	(0.111)	(0.122)	(0.137)	(0.089)*	(0.184)	(0.111)
Pseudo R-squared	0.173	0.159	0.203	0.497	0.585	0.693	0.266	0.206	0.284
Observations	323	324	323	323	324	323	323	324	323
Control variables included									
Community and time	YES	YES	YES	YES	YES	YES	YES	YES	YES
Socio-economic characteristics	YES	NO	YES	YES	NO	YES	YES	NO	YES
Baseline lighting consumption	NO	YES	YES	NO	YES	YES	NO	YES	YES

Note: p-values are displayed in parentheses, where *** p<0.01, ** p<0.05, * p<0.1 denote statistical significance. The dependent variable is log(WTP). We display marginal effects from a Tobit estimation. The base category is a one week payment period. To read the coefficients as percentage change in absolute values of WTP – rather than log(WTP), the coefficients have transformed as follows: 100* [exp(coeff) -1]. Table B.1 in the Appendix B shows the complete regression results including control variables.

It can be seen that effects of relaxing liquidity constraints are very consistent across the three kits. Offering a six weeks payment period instead of a 7 days payment period increases the WTP somewhat, but not considerably and not in a statistically significant way. For all three kits the 5 months treatment increases the WTP by 8 to 13 percent and the increases are at least borderline statistically significant.

How can these findings with respect to the different payment schemes be interpreted? The effect size is in each case very modest. Interest rates on local formal and informal capital markets are much higher than these increases in the WTP. Savings and Credit Cooperative Organizations (SACCOs), the most accessible formal source of financing, offer credits in rural Rwanda at interest rates of 2.5 to 5 percent monthly (AFR, AMIR & MicroFinanza Rating 2015). In fact, the monthly percentage changes in the WTP induced by the treatments are close to such interest rates. Hence, the positive treatment effect vanishes when discounting the WTP for a 2.5 percent monthly interest rate applied to each of the two treatments.

It might be that the payment schemes we offered are not long enough. Poor households might be particularly interested in payment schemes that enable them to make the investment without changing their over-time cash flow, which would require that the investment amortizes within the payment period. The stylized calculations we performed in Table 3 yield amortization periods of 15 months, 19 months, and 79 months for Kit 1, 2 and 3, respectively. While the shorter periods for Kit 1 and 2 might be realistic in a real-world setting, the 79 months for Kit 3 certainly is not. Nonetheless, the observation that participants' WTP does hardly respond to the 5 months extension of the repayment scheme suggests that credit constraints are not the major bottleneck hampering adoption of solar technologies.

5. Encashment challenges and cost-benefit analysis

In this section we interpret our findings in the light of the two perspectives outlined in the introduction. First, we focus on practical implications of our payment model for the market-based approach which is currently favored by the SE4All initiative and pursued by many governmental interventions. Second, we provide a back-of-the-envelope cost-benefit analysis to assess the welfare implications if public funds were used to subsidize the access to solar energy.

5.1. Encashment challenges

Households in our experiment received a 7 days, 6 weeks, or 5 months payment target and thereby received the kit before making any payment. This set-up resembles many existing business approaches of off-grid solar providers such as the pay-as-you-go model. Recall that we offered households to pay in small instalments via mobile money and without any mandatory advance payment. Participants did not receive a reminder before their respective payment period expired. In September 2016, i.e. around 14 months after the experiment, 65 percent of participants have paid the full price. This is a fairly high share in line with comparable exercises (see Tarozzi et al. 2014) and confirms that overall participants took the payment obligation seriously. Only 17 percent of customers, though, paid the full price on their own initiative and within their payment period. This share is highest at 37 percent in the one-week payment group compared to the six weeks (11 percent) and five months group (9 percent). Figure C in the Appendix C shows the payment behavior over time graphically.

After the expiration of the payment periods, our field team called the customers up to nine times over a period of approximately six months to remind them of open payments. In total, 488 reminder calls were made. The most typical response to these calls was a payment promise (over 50 percent), followed by referring to financial bottlenecks, sickness, dissatisfaction with mobile money, and misunderstanding of the contract (about 10 percent each). For participants in default, our field team additionally contacted community authorities and eventually revisited the defaulting participants to announce that the kit will have to be returned in case of further delays in payment. This encashment process increased the rate of fully paid kits considerably (from 17 to 65 percent). It is important to emphasize that all of these households were generally satisfied with the kit. At no point during this intense encashment procedure we were confronted with complaints about the kits' quality or statements indicating that people do not need the kit.

What are the implications for real-world dissemination of off-grid solar? Our approach is certainly not identical to the marketing approach of companies in the sector. In particular, technical innovations to turn off solar kits from afar can be an important tool to increase repayment rates. In general, however, we believe that the intensity of our encashment procedure was rather higher than what is feasible in commercial approaches. Consequently, the induced overheads resulting from high transaction costs and default rates have to be borne by the companies.

Overall, this further supports our interpretation above; it will be difficult to reach the poor with a solely market driven approach. In addition to the general affordability problems transaction costs to collect outstanding payments are high to cater this customer group.

5.2. A stylized cost benefit-analysis

For the cost-benefit analysis we take the perspective of a welfare planner and, following Lee et al.'s (2016) approach, ask what would be the social cost-effectiveness if full access was ensured by a subsidy that reduces the end-user price to zero. We contrast the costs of such an intervention with the benefits as reflected in the revealed WTP. For Kenya, Lee et al. (2016) estimate a welfare loss from grid intensification, depending on the connection rate within a community among others, of between 511 USD and 1,100 USD per household. Our case differs in one important way: Unlike grid extension, off-grid solar is detached from physical networks, and hence we do not need to determine the social costs per community and in general require less assumptions because of a less complex cost structure. We can simply use the solar kits' market price as an acceptable approximation of supply side costs (see Table 6). To approximate the benefits of solar kit usage we take the average WTP observed in our sample. In line with our observation in Section 4.2, Table 6 shows that the average costs clearly exceed average benefits, yet the resulting social costs per household are far below those of on-grid electrification.

Table 6: Costs and Benefits of off-grid electricity per household

	Kit 1	Kit 2	Kit 3
Costs in USD	12.88	37.35	180.32
Benefits in USD	4.90	16.66	96.93
Social costs in USD	7.96	20.69	83.39

Note: Tobit corrected WTPs are used, see Table 4.

If we interpret the upper price bound in Figure 3 (Section 4.2.), i.e. the kits' market prices, as the supply curve, one notes that it only crosses the demand curve, if at all, at very low adoption rates. In this graph, the benefits from solar kits at any coverage and price level are given by the area below the demand curve. In a free-distribution program this is what the social welfare planner would perceive as benefits of the program. By contrast, the area between the demand curve and the cost line reflects the social costs, i.e. costs that are not covered by benefits. On average, these social costs amount to the values displayed in Table 6, i.e. 8 USD per household for Kit 1, 21 USD for Kit 2, and 83 USD for Kit 3.

Is the assumed supply curve plausible? The prices we use in Table 6 and Figure 3 are Rwandan retail prices at which real-world off-grid solar companies offer these products, also in remoter areas. Thus, they comprise not only costs of the hardware, but also logistical costs. In addition, we abstract from potential economies of scale, which is justified by the fact that fixed costs in solar kit provision are low and transport routes relatively short in the densely populated country. Furthermore, the market is perceivably competitive, with at least 25 providers of equal or similar solar kits based in Kigali so that high monopoly profits are unlikely.

Does the WTP measured here reflect all benefits provided by solar kits? This might not be the case for three reasons: First, households certainly do not account for social benefits that materialize elsewhere. These are, for example, reductions in environmental damage caused by non-electrified households who increasingly switch from kerosene to dry-cell batteries for lighting and dispose of batteries inappropriately in pit latrines or nature (see Bensch et al. 2015, Grimm et al. 2016 and Lenz et al. 2017). Furthermore, solar kit usage might trigger positive spillovers to neighbors who seize the lighting, the radio, or the phone charging opportunity. Second, households' WTP might not reflect all private benefits from solar kit usage. For example, households switching from kerosene to solar lighting might not assign a monetary value to the cleaner air and the related reduction in health hazards as well as the improved studying and working conditions. Also, scattered information about the product and potential benefits in the long run might prevent a full reflection of private benefits in the WTP. Third, households might face budget constraints that do not allow them to spend an amount equivalent to the benefits they assign to solar technologies. Having in mind that already the revealed WTP accounts for 20 to 343 percent of the households' monthly expenditures, it becomes clear that the amounts dedicated to the solar kits cannot be easily raised by a poor target group. At the contrary, it is likely that households have other essential investment requirements impeding them to dedicate more money to solar technologies, even if they wished to do so. Given the households' irregular income patterns as well as their liquidity and credit constraints, households' WTP is probably lower than their appreciation of the technologies. To the degree to which these factors lead to a downward bias of the revealed WTP in our approach we would underestimate the true benefits of off-grid solar and thus overestimate the social costs.

The next question now is whether public investments into the distribution of off-grid solar are worthwhile. This would be the case as soon as the external effects and non-internalized private benefits that accrue during the lifetime of a solar kit amount to around 8 USD, 21 USD, and 81 USD, respectively. While it is clearly beyond the scope of this paper to come up with a precise and comprehensive cost-benefit analysis, research on the impacts of off-grid solar suggests that benefits are sizable related to costs. Grimm et al. (2016) and Samad et al. (2013), for example, find that households do not only reduce energy expenditures quite considerably. There is also evidence for effects on productivity of housework activities, health, environmental outcomes, study time of children, and women’s decision-making abilities. These benefits are quite likely to cover the social costs and hence to make the investment worthwhile.

6. Conclusion

We have examined the willingness to pay (WTP) of rural households for three different solar lighting devices. We also explored the causal effect of randomized payment schemes on the WTP. We find that the WTP for the three solar devices – a 0.5 Watt solar lantern, a 3.3 solar kit and a 20 Watt solar home system – are clearly below their respective market price. The average WTP covers between 38 and 52 percent of the market prices and only very few households made a bid that comes somewhat close to it. The lesson that can be taken away from this experiment is that a solar technology distribution approach based on the private market alone is unlikely to reach the broader population in remote poor areas. The vast majority is not able to pay cost-covering prices. Relaxing credit constraints does not seem to be a panacea. This suggests that the ambition of the United Nations' initiative Sustainable Energy for All (SE4All) to disseminate off-grid solar to the rural poor via unsubsidized markets might be overly optimistic.

It is very possible, though, that smarter payment schemes with longer payment periods, for example shaped as a pay-as-you-go offer, work better to facilitate the household investment into off-grid solar. Moreover, remote monitoring systems can considerably bring down transaction costs in rural solar markets. An integrated micro-chip allows for a monitoring of solar kits without doing costly trips to the customer and even enables the marketing company to turn the kit off in case of non-payment. However, the evidence we present in this paper suggests that even those modifications and innovations will not solve the affordability issues of the poorer strata, which is also confirmed for the "pay-as-you-go-scheme" evaluated in Collings and Munyehirwe (2016).

It is worth noting that our analysis of the WTP for solar kits took a rather static perspective. As solar kits diffuse into the communities, peer effects and social learning are expected to affect both, the level of the WTP and the role of non-financial adoption factors. Moreover, Rwanda might not be representative for other Sub-Saharan Africa countries due to its huge and effective electricity grid extension program EARP. Since EARP reaches out even to the periphery of the country, communities left over for off-grid solar electrification are very remote. In other countries' regions, less remote and possibly not that poor, communities will qualify for off-grid solar electrification and the WTP could well be a bit higher there.

Over and above, however, the qualitative direction of our results will be transferable to other African countries. A considerable share of the rural population not connected to the grid will not be able to bring up the full market price. If these strata are to be reached, which is the explicit goal of the SE4All initiative, the introduction of subsidies needs to be considered. Following the approach used by Lee et al. (2016), we have also shown that the `social costs´ of fully subsidizing off-grid solar are much lower than for on-grid electrification. Service levels for off-grid solar are of course too low to expect any substantial commercial usage, yet, earlier research has shown that electricity consumption levels even in grid-connected areas in Africa are very modest and productive usage is rare (see, for example, Lenz et al. 2017 and Peters et al. 2011). Such consumption levels can well be accommodated by off-grid solar. In fact, Grimm et al. (2016) as well as Samad et al. (2013) provide evidence for pro-poor impacts of off-grid solar that are noteworthy given the low investment costs. It is likely that some of these benefits are not internalized, and hence not captured by our WTP values, because they occur only in the very long run or as external effects. It is also worth to mention that the WTPs we measure are low in absolute terms but they are quite considerable in relation to the expenditure levels of the target group indicating that households give off-grid electricity priority over many other (important) goods. Again, from a welfare's planner perspective, this makes a case for a policy intervention to facilitate adoption.

For policy a reasonable way forward to reach the rather short-term universal access goals could therefore be to provide off-grid solar to rural households in Africa at subsidized prices. Instead of rolling out the grid to every rural village in Africa, on-grid investments could be concentrated on certain prospective regions with high business potentials or industrial zones to which firms might relocate. Such an integrated on-grid-off-grid strategy would enable industrial development and at the same time achieve broad access to electricity at relatively low costs.

Appendix A: Experiment Instruction

Maintenant je vous invite à acheter le kit que je vous ai présenté. La vente se distingue des ventes usuelles, car le prix n'est pas encore fixé. La vente fonctionne comme suit. Vous allez me donner une enchère pour le kit, donc une somme pour laquelle vous voulez bien acheter le kit. Il est bien d'indiquer la somme maximale que vous êtes prêtes à payer. En faisant votre enchère rappelez-vous que vous dépensez tous les mois d'un certain montant pour l'énergie afin d'éclairer votre maison, par exemple pour les batteries, les bougies ou le kérosène. Pour toutes ces sources d'énergie, en Ruanda rurale, on dépense en moyenne 2600 RWF par mois. Vous pourriez économiser donc cet argent en utilisant un kit solaire. Le kit solaire ne coute plus rien après la vente. Quand vous avez fait votre enchère on va tirer un de ces enveloppes pendant une réunion au village cette après-midi. Chaque enveloppe indique un prix. Si ce prix est <u>plus élevé</u> que votre enchère, vous ne pouvez pas acheter le kit. Si le prix qu'on tire est <u>moins élevé</u> que votre enchère, vous allez acheter le kit pour <u>ce prix</u>. Vous avez seulement la possibilité d'enchérir une fois et vous ne pouvez pas changer votre enchère. Donc, si votre enchère est moins élevée que le prix qu'on tire, vous ne pouvez pas acheter le kit solaire. Depuis la vente, on va signer un contrat de vente aujourd'hui et au cas où vous ne pouvez pas payer pour le kit toute-de site, nous retournons dans trois semaines pour collecter l'argent. Si vous voulez, vous pouvez payer déjà une avance. Donc, s'il vous plait faites une enchère que vous pouvez payer dans au plus tard trois semaines. Nous n'allons pas partager votre enchère avec d'autres, il restera le résultat d'un jeu confidentiel.

Je vous donne un exemple de telle sorte que vous pouvez bien comprendre la façon de vente. Imaginez qu'on vendait un téléphone portable de la même façon. Vous pourriez par exemple dire que vous êtes prêtes à payer une somme de 3000 RWF pour le portable. Ensuite on tire une enveloppe.

- L'enveloppe pourrait par exemple contenir un prix de 2000 RWF. Qu'est-ce-qui se passerait dans ce cas-là ? *[Attendez la réponse; réponse correcte: on vendrait le téléphone portable pour 2000 RW]*
- Qu'est-ce-qui se passerait si vous enchéririez 3000 RWF et on tire une enveloppe de 3500 RWF ? *[Attendez la réponse ; réponse correcte: le téléphone ne se peut pas acheter. Expliquez encore une fois dans vos propres mots si nécessaire ; demandez s'il y a toujours des questions, faites un autre exemple hypothétique avec un produit imaginaire (pas un kit solaire) si nécessaire.]*

Rappelez que vous ne pouvez pas changer votre enchère après qu'on tire au sort et que vous pouvez enchérir seulement une fois. Rappelez aussi que vous devez payer le prix réellement dans une semaine. En plus soyez conscient de que vous ne pouvez pas acheter le kit même si votre enchère est seulement un tout petit peu moins élevée que le somme qu'on tire. *[Vérifiez s'il y a toujours des questions. Demandez pour la première enchère, assurez-vous que le participant en est sûr.]*

Appendix B: Regression results

Table B.1: Detailed regression results of Table 5

	Kit 1			Kit 2			Kit 3		
Payment periods									
Payment period: 6 weeks	0.012	0.021	0.023	0.049	0.044	0.056	0.060	0.065	0.058
	(0.801)	(0.633)	(0.627)	(0.333)	(0.367)	(0.256)	(0.240)	(0.203)	(0.245)
Payment period: 5 months	0.119	0.106	0.111	0.086	0.076	0.073	0.085	0.067	0.080
	(0.011)**	(0.037)**	(0.017)**	(0.111)	(0.122)	(0.137)	(0.089)*	(0.184)	(0.111)
Socio-economic characteristics									
Female respondent	-0.028		-0.020	-0.045		-0.052	-0.054		-0.056
	(0.515)		(0.645)	(0.181)		(0.112)	(0.060)*		(0.035)**
Hoh years of education	0.014		0.014	0.013		0.011	0.007		0.007
	(0.033)**		(0.050)*	(0.001)***		(0.005)***	(0.122)		(0.171)
HH size	-0.022		-0.023	-0.019		-0.021	-0.002		-0.002
	(0.085)*		(0.079)*	(0.120)		(0.124)	(0.843)		(0.815)
Hoh is a farmer	0.060		0.054	-0.022		-0.016	0.034		0.040
	(0.131)		(0.105)	(0.478)		(0.597)	(0.478)		(0.444)
Share of students in HH	0.001		0.001	-0.000		0.000	0.001		0.001
	(0.310)		(0.460)	(0.989)		(0.869)	(0.045)**		(0.026)**
House with tile roofing	0.211		0.184	0.026		-0.020	0.052		0.049
	(0.117)		(0.146)	(0.715)		(0.768)	(0.469)		(0.466)
Monthly non-energy expenditures (USD) [1,2]	0.000		0.000	0.000		0.000	-0.000		-0.000
	(0.740)		(0.823)	(0.198)		(0.846)	(0.696)		(0.496)
Baseline energy consumption									
Monthly phone charging expenditures (USD)[1]		0.016	0.010		0.057	0.056		0.013	0.012
		(0.341)	(0.571)		(0.000)***	(0.000)***		(0.151)	(0.180)
Monthly energy expenditures (USD)[1,3]		-0.001	-0.001		0.000	-0.000		-0.000	0.000
		(0.141)	(0.256)		(0.792)	(0.789)		(0.922)	(0.599)
Ownership of car battery		0.142	0.112		0.069	0.061		0.038	0.018
		(0.339)	(0.300)		(0.653)	(0.687)		(0.370)	(0.704)
Ownership of rechargeable lamp		0.132	0.139		0.054	0.048		0.048	0.039
		(0.028)**	(0.013)**		(0.302)	(0.373)		(0.218)	(0.388)
Ownership of solar kit		-0.068	-0.056		-0.126	-0.122		-0.018	-0.031
		(0.226)	(0.363)		(0.006)***	(0.023)**		(0.640)	(0.457)
Pseudo R-squared	0.173	0.159	0.203	0.497	0.585	0.693	0.266	0.206	0.284
Observations	323	324	323	323	324	323	323	324	323

Note: p-values are displayed in parentheses, where *** p<0.01, ** p<0.05, * p<0.1 denote statistical significance. The dependent variable is log(WTP). We control for payment period, community and time fixed effects, and socio-demographic characteristics. Dummy variables taking the value 1 are indicated by "= 1". [1] The values are bottom and top coded at 2% and 98% of the distribution respectively to eliminate the effect of outliers. [2] Excluding energy and phone charging expenditures. [3] Including expenditures on kerosene, gas, batteries, candles and charcoal; excluding expenditures on wood and rechargeable lamp charging.

Table B.2: Detailed regression results of Table 5 for restricted sample

		Kit1			Kit 2			Kit 3	
Payment periods									
Payment period: 6 weeks	0.014	0.011	0.021	0.034	0.043	0.050	0.067	0.066	0.061
	(0.807)	(0.854)	(0.712)	(0.585)	(0.482)	(0.384)	(0.207)	(0.202)	(0.235)
Payment period: 5 months	0.118	0.111	0.109	0.103	0.092	0.082	0.086	0.094	0.087
	(0.049)**	(0.024)**	(0.024)**	(0.107)	(0.139)	(0.114)	(0.074)*	(0.045)**	(0.049)**
Socio-economic characteristics									
Female respondent		-0.052	-0.043		-0.059	-0.062		-0.042	-0.047
		(0.280)	(0.360)		(0.150)	(0.087)*		(0.171)	(0.086)*
Hoh years of education		0.012	0.013		0.014	0.011		0.007	0.005
		(0.036)**	(0.049)**		(0.002)***	(0.025)**		(0.074)*	(0.164)
HH size		-0.034	-0.035		-0.023	-0.029		0.005	0.003
		(0.008)***	(0.008)***		(0.089)*	(0.050)**		(0.630)	(0.755)
Hoh is a farmer		0.067	0.064		-0.037	-0.014		0.082	0.104
		(0.099)*	(0.131)		(0.296)	(0.709)		(0.141)	(0.075)*
Share of students in HH		0.002	0.001		0.000	0.000		0.000	0.001
		(0.140)	(0.251)		(0.942)	(0.968)		(0.462)	(0.342)
House with tile roofing		0.142	0.127		-0.025	-0.052		0.046	0.055
		(0.102)	(0.158)		(0.719)	(0.469)		(0.609)	(0.502)
Monthly non-energy expenditures (USD) [1,2]		0.000	0.000		0.000	-0.000		-0.000	-0.000
		(0.514)	(0.653)		(0.448)	(0.861)		(0.911)	(0.522)
Baseline energy consumption									
Monthly phone charging expenditures (USD)[1]			0.009			0.058			0.020
			(0.662)			(0.000)***			(0.016)**
Monthly energy expenditures (USD)[1,3]			-0.001			-0.000			0.001
			(0.329)			(0.757)			(0.161)
Ownership of rechargeable lamp			0.129			0.122			0.059
			(0.053)*			(0.152)			(0.240)
Pseudo R-squared	0.207	0.178	0.231	0.378	0.529	0.676	0.192	0.272	0.318
Observations	277	277	277	277	277	277	277	277	277

Note: p-values are displayed in parentheses, where *** p<0.01, ** p<0.05, * p<0.1 denote statistical significance. The sample is restricted to households that do not own a modern electricity source, i.e. a car battery or a solar kit. The dependent variable is log(WTP). We control for payment period, community and time fixed effects, and socio-demographic characteristics. Dummy variables taking the value 1 are indicated by "= 1". [1] The values are bottom and top coded at 2% and 98% of the distribution respectively to eliminate the effect of outliers. [2] Excluding energy and phone charging expenditures. [3]Including expenditures on kerosene, gas, batteries, candles and charcoal; excluding expenditures on wood and rechargeable lamp charging.

Appendix C: Payment behavior over time

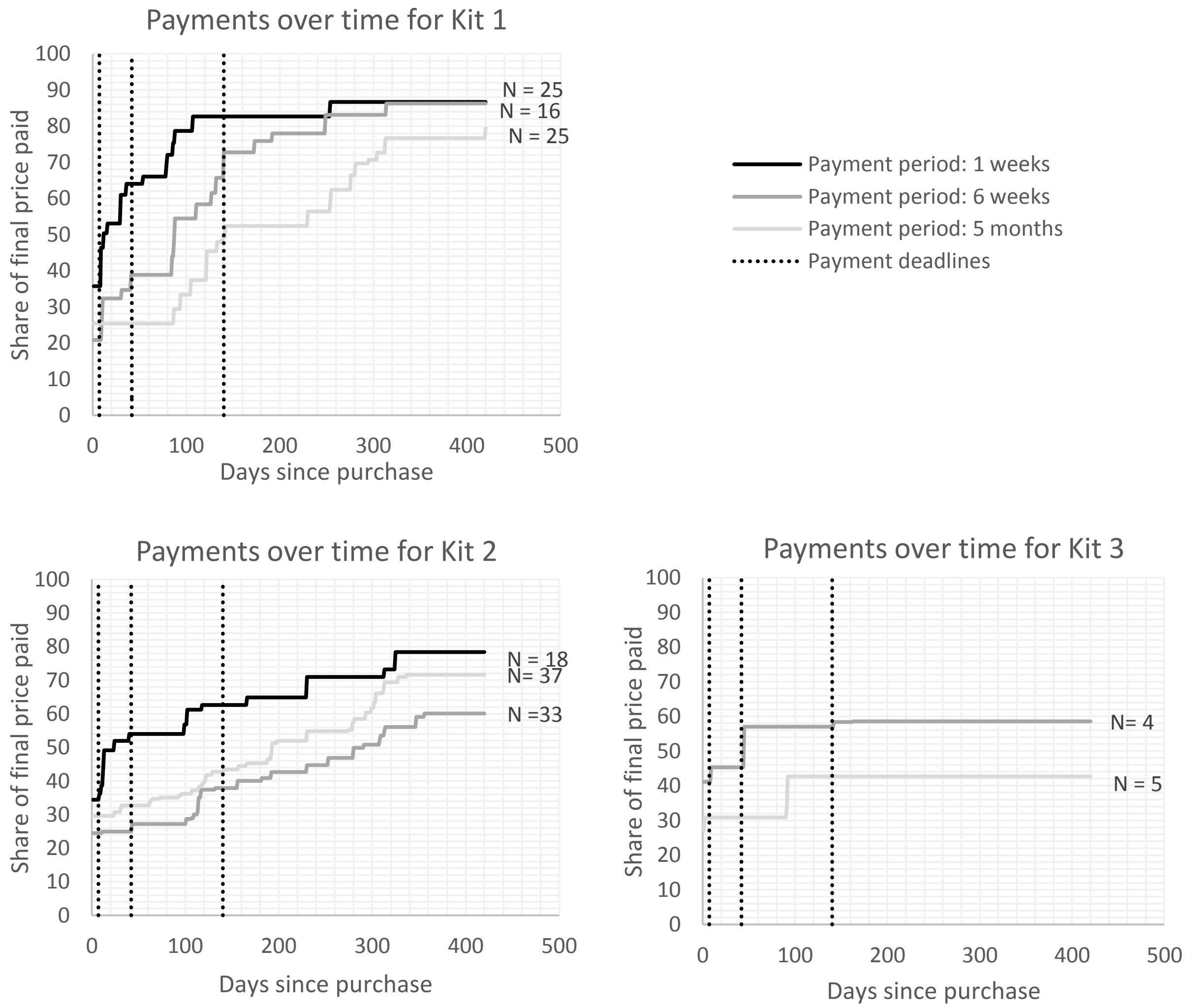

Figure C: Payment receipts over time

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