University of Strathclyde Glasgow

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Shedding Light on the Last Mile: A study on the Diffusion of Pay As You Go Solar Home Systems in Central East Africa

Jack Barrie[1,2*], Dr. Heather J Cruickshank[1,3]

1. Centre for Sustainable Development, University of Cambridge
2. Civil and Environmental Engineering Department, University of Strathclyde [Permanent]
3. Smart Villages Initiative, University of Cambridge & University of Oxford

* Corresponding author

Abstract

Approximately 1.2 billion people lack basic access to electricity. The United Nations 'Sustainable Energy for All' initiative exemplifies the urgent need to address this issue. Recent advancements in photovoltaic, light emitting diode and battery technology have resulted in the rise of affordable and innovative household electricity technologies, however penetration rates remain low due to complexity surrounding 'last mile' distribution. This paper applies the diffusion of innovations theory as a framework to investigate the 'last mile' challenges encountered when launching a Pay As You Go Solar Home System in a region of Central East Africa. The results indicate that Pay As You Go offers the potential to deliver a disruptive positive impact with regard to increasing access to clean affordable energy for the poor, however, both the technology and business model are more complex than current alternatives and therefore require a much more developed go-to-market strategy. The cost of achieving widespread diffusion is therefore higher than similar products sold at retail, yet this is balanced by potential for a much faster rate of adoption. Finally, this paper demonstrates the applicability of the diffusion of innovations theory as a viable framework for analysing last mile challenges associated with Solar Home Systems.

Key words: Solar Home System, Pay As You Go, Rural Electrification, Diffusion of Innovations

1. Introduction

Electricity is the universal carrier of energy and the backbone of modern society. It contributes up to 17% of all global energy demand and provides critical services such as lighting, refrigeration and appliance power that would be difficult to provide using alternative energy sources (IEA, 2011). Approximately 1.2 billion people, a fifth of the world's population, lack access to electricity (Practical Action, 2014). Lack of access to electricity is not spread evenly across the global population. Sub-Saharan Africa and developing Asia account for more than 95% of the global total, in which over 85% reside in rural areas (SE4All, 2013). Ensuring universal access to sustainable and affordable energy is therefore essential for ending all forms of poverty, fighting inequalities and tackling climate change.

This was reflected in the establishment of Sustainable Development Goal #7 which aims to ensure access to affordable, reliable, sustainable and modern energy for all. Increasing access to modern electricity is a core objective within this goal. A body of literature now exists that corroborates the need for gaining access to electricity and achieving development goals (Practical Action, 2013; Practical Action 2014; Bhattacharyya, 2012; SE4All, 2013; United Nations, 2013). Electricity offers access to basic yet necessary services such as lighting, communications and water supply; social services such as healthcare, education, public institutions and public infrastructure; and income generating activities such as manufacturing and food processing (Practical Action, 2013).

In addition, users of traditional fuels for lighting are continually exposed to harmful gasses such as carbon monoxide (CO), nitric oxide (NOx), and sulphur dioxide (SO_2) which can result in serious health issues such as impaired lung function, asthma, and cancer (Lam, *et al.*, 2013).

With regard to the environmental damage, Mills (2005) estimates that globally, 77 billion litres of fuel are used annually just for lighting; the majority of which occurs in sub-Saharan Africa. This results in 190 million metric tons of CO_2 emissions each year, or 7% of global black carbon emissions (Lam, *et al.*, 2013). As well as carbon emissions, traditional fuel use results in approximately 6.5 million hectares of forest being felled annually to meet demand (Practical Action, 2014). Traditional fuels are also stifling economic growth in low income countries. Poorer households can expect to pay up to a third of their income on traditional fossil fuels and rural consumers often pay a premium of approximately 35% over urban consumers who are able to buy in larger quantities (Lighting Africa, 2012).

Significant advancements in battery, light emitting diode (LED) and photovoltaic (PV) technology combined with the widespread adoption of mobile phones, has led to a significant growth in market driven household electricity generation devices (Rippey & Nelson, 2011). An estimated one million devices have been sold globally and the market is predicted to grow by up to 300% in the next decade (Lighting Africa, 2012). The International Finance Corporation (IFC) estimates that the household lighting market for the world's poor may be worth $37 billion (IFC, 2012).

Within the household electricity supply market there are currently three main categories that are experiencing the biggest drive in market led innovation: (i) household devices; (ii) community level mini-utilities; and (iii) grid-based electrification (IFC, 2012). The IFC estimates that household devices can address around 85% of the potential immediate household electricity market, with community level mini-utilities (10%) and grid (5%) making up the rest (IFC, 2012). There is therefore a potential for a rapid transition away from traditional centralised electricity generation and transmission through a national grid to a more resilient and efficient electricity system where electricity is generated and potentially owned locally. Such a rapid and disruptive transition also requires significant adjustments to national energy policy – for example adjusting grid rollout plans based on the predicted rapid diffusion of decentralised energy generation devices.

Household devices such as solar lanterns and kits are limited to very low electricity generation levels (Bond, *et al.,* 2010). However, solar home systems (SHS) offer the potential to cover a much broader spectrum of energy applications (2W-80W) as well as to bridge the gap between solar kits and grid-based power sources. Furthermore, due to several recent innovations in SHS business models becoming service rather than technology orientated, for instance using pay as you go (PAYG) credit schemes, their affordability is now comparable to solar kits and lanterns (IFC, 2007). Although the power generation from SHS is currently far lower than the grid supply, continually falling solar, battery and mobile phone prices combined with innovative market driven business models such as the "PAYG energy escalator", offer the potential to leapfrog the expensive deployment of the grid in rural regions which in some cases may take decades to roll out (IRENA 2016).

Even though the household electricity market is predicted to grow rapidly, penetration of SHS remains low and may be considered a niche innovation (Lighting Africa, 2012). A number of SHS programmes have been undertaken in developing countries, yet Holtorf *et al*,. (2015) highlight that only a few appear to be successful.

A recent survey by Patel (2014), of over 1000 energy access practitioners identified three key reasons for low penetration: (i) a lack of patient capital made available by financial institutions due to the immaturity of the market; (ii) the energy policies set by Governments; and (iii) 'last mile' scaling challenges.

This paper addresses an area believed to be least understood within the field of energy policy - the 'last mile' scaling challenges of SHS. The term 'last mile' encompasses the most challenging aspect of delivering rural electrification which is delivering a product or service from a local urban centre to individual customers. The 'last mile' can be considered the interface between the customer and the company and encompasses many challenges ranging from poor transport infrastructure and tight product margins all the way through to managing and understanding customer perceptions and demands (USAID, 2011).

There now exists a period of rapid innovation within the sector with regard to the variations in technologies and business models that are being trialled in order to overcome the 'last mile' hurdle (IFC, 2012). Current service models in development include rental, 'energy escalators', pay as you go and microfinance (Friebe, *et al.*, 2013). Due to the immaturity of the market, there is not yet a standardized nor dominant service delivery methodology and little literature exists that outlines the barriers to rapidly scaling up these models. One of the most dominant delivery models of SHS is through a Pay As You Go (PAYG) scheme.

The PAYG SHS business model offers significant benefits over the traditional retail model as it allows customers to pay for the SHS in affordable chunks. For the PAYG SHS in this study, the customer is expected to make a small upfront financial commitment ~USD$10 to have the system installed at their house. Once installed, the customer is then expected to pay weekly, either through scratchcards or mobile money to access lighting and phone charging, at the cost of circa USD$1.25 per week. If the customer successfully tops up weekly for 105 weeks the system permanently unlocks. If the user does not add credit to the system once in a 4 week period they are classed as a defaulter. By defaulting, the user runs the risk of having the unit reclaimed by the distributor.

The last mile challenges associated with PAYG are far greater than traditional retail models as the SHS distributor is required to retain a long-term relationship with each customer as well as provide support services, such as system maintenance, to ensure the customers make regular payments. This paper applies the diffusion of innovations theory as a framework to understand a broad range of challenges with last mile distribution of PAYG SHS and highlights the need for policy to help overcome such challenges.

2. Diffusion of Innovations Theory

The diffusion of innovations theory can be used as a framework to explain why, how and at what rate new ideas and technologies permeate through cultures (Rogers, 2003). It is a theory that encompasses not only the variables that affect the adoption of an innovation, but also the characteristics of the innovation adopters. It offers a framework to explore how an innovation is perceived to be consistent with socio-cultural values and helps provide clarity on the innovation decision process experienced by the potential adopter. A number of recent studies have demonstrated the benefits of applying the diffusion of innovations theory as a framework to explore the challenges with scaling renewable energy provision in developing countries (Holtorf, *et al.,* 2015; Urmee 2016; Velayudhan 2003; Zanello, *et al.,* 2016; Mceachern & Hanson 2008), however, none has applied it to analyse the diffusion of PAYG SHS. The aim of this paper is to explore the challenges related to achieving widespread diffusion of PAYG SHS and identify the potential role of policy in overcoming such challenges. By adopting the diffusion of innovations theory as a framework, this paper aims to explore both the role of the distributor in designing an appropriate diffusion model, but also socio-cultural variables that influence the rate of adoption. It also offers a useful framework for policy as it explores challenges experienced not only at the individual business strategy level, but also the broader societal level.

2.1. Variables that affect innovation adoption rate

Through numerous quantitative studies, Rogers (2005) theorizes that there are five main attributes of an innovation that influence the rate of adoption: (i) the relative advantage it offers compared to the technology or service it replaces; (ii) compatibility with the customer lifestyle; (iii) complexity; (iv) trialability; and (v) observability. As in a similar paper on the diffusion of innovations in developing countries by Roman & Hall (2004) and discussed in Rogers (2003) and Tornatzky & Klein (1992), the two final attributes, trialability and observability, were not analysed since as they are not considered as influential as the first three variables which are the focus of this paper (Table 1).

As well as the innovation attributes, this paper investigates the influence of two further variables: (i) the communication channels; and (ii) the social system (Table 1). These were selected because the main communication channels used during this study were direct group promotional events and interpersonal communication through local sales agents which had a significant impact on the rate of adoption. The social system of the customers varied from rural to dense urban populations.

2.2. Limitations of Diffusion of Innovations Theory

Although the diffusion of innovations theory has been widely accepted and adopted, there are key limitations. A paper by Sultan and Winer (1993) argues that an individual may be an innovator for one innovation and a laggard for another. With reference to this paper, however, it is assumed that the significance of this limitation will be low as it only assesses one innovation rather than compare the results with different innovations and all the PAYG systems distributed in this case study were identical. Furthermore, this paper uses a qualitative field level survey and only uses the diffusion of innovations theory as a general guide for empirical enquiry. In addition to this, Rogers (2003) outlines two common limitations of the theory: (i) the pro-innovative bias; and (ii) the recall problem. This research overcomes the individual recall problem by using server data to determine the exact date of adoption instead of relying on each customer recalling when they adopted the innovation. It does not consider that the pro-innovative bias is a key limitation as data collection was carried out by an agent external to the proprietor or distributor of the innovation with the aim of investigating the issues surrounding the diffusion of the innovation.

3. Aims and Objectives

There is a growing body of literature on the development of Pico-PV technologies and their associated business models (Lighting Africa, 2012; Friebe, *et al.*, 2013; Jacobson, 2007; Lay, *et al.*, 2013; van der Vleuten, *et al.*, 2007; International Finance Corporation, 2012; D-Light, 2012; Rolffs, *et al.*, 2014). Whilst these studies identify the range of possible business models and technologies, few have undertaken field level studies on the challenges associated with the diffusion of these technologies.

The aim of this paper is to assess the key variables that influence the diffusion of PAYG SHS in a region of Central East Africa over the period of one year. These include the adoption attributes of complexity, relative advantage and compatibility as well as the social system that exists and the communication channels used by the distributor. In order to develop a broad assessment of these attributes, the paper examines two key aspects of the customer adoption process: (i) the initial adoption of the SHS; and (ii) the long-term socio-technical relationship that customers have with the technology.

4. Methodology

4.1. Region of Study

This research assesses the challenges associated with the last mile diffusion of PAYG SHS in a region of Central East Africa. The distributor began selling the PAYG SHS in the region beginning March, 2013, and identified it as being the most challenging of countries with which to scale operations.

The region currently experiences some of the lowest levels of access to electricity in the world and has one of the largest populations without access (World Bank, 2014). Currently, 85% of the population lack access to electricity, which is well above the average for both SSA and low income countries in general (World Bank, 2014). Grid access is largely only available to the urban population in this region.

The region is also facing significant environmental, social and economic consequences as a result of this. Roughly 90% of the population relies on traditional fuels such as kerosene and local biomass as a primary energy source. This has resulted in nearly 40% of native forest being felled between 1990 and 2010 (Eder, 2013). Furthermore, the rural poor are paying up to twice as much for their energy compared to people with grid access and are exposed to the risks of using traditional fuels such as smoke inhalation and burn injuries.

4.2. Data Collection

The data for this paper was collected from two discrete sources: (i) raw server data from SHS sales of the region; and (ii) field based interviews and observations. The server data was analysed based on two key adoption characteristics of the customer: (i) the initial adoption of the SHS; and (ii) the customers' payment pattern with the SHS once it was in their possession. The field data was analysed to capture the customer perceptions of the SHS. Based on this analysis, the key diffusion of innovation theory rate of adoption variables for the SHS were assessed (Figure 1).

4.2.1. Server Data Collection

The server is owned and maintained by the PAYG SHS provider and records two types of data related to the sales of the PAYG SHS: (i) the purchase log; and (ii) the transaction log.

The purchase log is a record of information regarding the customer's purchase of the PAYG SHS including the customer GPS location, name, gender, contact details, the installer's name, and date of install and the serial number of the PAYG SHS unit installed. This data is recorded manually by each individual distributor. The purchase log is updated manually by the distributor's sales team which resulted in a number of blank or inaccurately entered fields. The purchase log listed only half of units identified in the transaction log. This meant that only 747 units out of 1,376 units had installation dates assigned to them. Furthermore, when comparing the first install dates with the first top-up date for a specific unit, it was found that over 20% of the install dates were later than the first top-up date.

The install date for each unit was therefore taken as first top-up transaction. This was a valid assumption as all units are sold with a pre-paid scratchcard and thus the majority of customers top-up on the same day the SHS is installed. This assumption was also validated by the field staff during the field study.

The transaction log automatically records data about every transaction from every unit. This includes the date and time of the transaction. The transaction log was fully automated and thus there were few formatting requirements. The log contained data for 1,376 units and 13,532 unit transactions. The raw datasets were downloaded from the server. Only information recorded between 1st March 2013 and 1st April 2014, a period of 56 weeks, was selected as that corresponded with the purchase of the first PAYG SHS unit.

4.2.2. Server Data Analysis

4.2.2.1. Initial Adoption Characteristics

The number of units adopted by customers every week is calculated by using the date of install to calculate the number of units adopted per week as well as the cumulative number of units adopted. Both the weekly and cumulative adoption rates were then plotted against time.

4.2.2.2. Long Term Adoption Characteristics

The following default characteristics were calculated for each customer: (i) whether they had defaulted; (ii) the risk of defaulting based on their pattern of use in the first 12 weeks after installation. Default in this case means when a customer fails to top-up the PAYG SHS for four weeks in a row. In order to determine the default rate for each customer a new dataset was created whereby the number of transactions per week for each customer (identified by the unique serial number) were plotted between the 1st March 2013 and 1st April 2014. A unit's credit status could then be calculated using the weekly top-up data to form a running total of credit availability. Therefore, when a positive value, or 0, is present, the customer is in credit. If a negative value is present then the customer is out of credit by the corresponding number of weeks (Table 2).

In order to calculate the risk of a customer defaulting, based on their first 12 weeks of usage, a separate dataset was created which listed the first 12 weeks credit status of any customer with a minimum of 12 weeks usage which totalled 965 units. The dataset was split into two categories, units that had been adopted before and after 1st November 2013 which corresponded with the change in sales strategy. The percentage of units classed as 'out of credit' for each week was calculated based on the definition of default as being four weeks out of credit.

4.2.3. Rationale for field level case study

Although quantitative analysis was undertaken on raw data collected from each unit transaction, the field level case study provided qualitative data via structured and semi-structured interviews. This was undertaken in order to verify and expand on the initial server data analysis and to understand a current phenomenon in its real-life context, particularly as the boundaries between phenomenon and context are not clearly evident (Yin, 2014). The field level case study was carried out over the period 2nd May 2014 - 23rd May 2014. The field level survey was comprised of three main components:

(i) *Field level observation of the entire distribution, sales and customer support processes.* This included shadowing office staff responsible for general administration and customer service and installation technicians responsible for installing and marketing the units.

(ii) *A survey of key geographical regions.* This included investigating two areas displaying severe levels of defaulting and one displaying slow but steady adoption and use.

(iii) *Interviews with both key customer agents and a spectrum of different customers.* This included interviews with 27 defaulting customers and eight local customer agents. In order to overcome language and cultural barriers, interviews were conducted with the regional manager of the distributor acting as the translator. This served two benefits: firstly, the regional manager spoke fluent English and Swahili, and secondly, interviewees fully understood the purpose of the survey thus reducing the risk of important respondent feedback being excluded. To reduce the risk of blurring of information, whereby survey respondents, whether purposely or innocently, provide information that is false, the surveys included 'shadow' questions whereby the interviewee was asked the same question twice, but the second question was reversed.

4.3. Data Limitations

The dataset spans a period of 56 weeks, roughly half the time expected for a customer to pay off the total cost of a system. The research, therefore, was unable to investigate transaction characteristics over the entire payment lifecycle of the SHS. With regard to the limitation of mapping the data, only 448 units had GPS coordinates assigned to them which limited the representativeness of the adoption and default maps produced. Therefore the maps were only used as an indicator of characteristics, for which specific investigations were verified through further analysis of the server data. During the early stages of sales, GPS collection was not done thoroughly and thus, on a number of occasions, clusters of points were located on top of one another, suggesting that the recorder entered them all at the same place. All the clusters, however, existed within close proximity to the actual location of the unit.

5. Results

5.1. General Adoption Characteristics

Three distinct phases in the diffusion of the PAYG SHS in the region were identified. As seen in Figure 2, Phase A represents the period in which the local distributor did not have a core marketing approach and had not yet developed promotional events, and thus they sold units in small numbers to customers from their shop. Phase A customers were comprised of 87% (200) urban dwellers and 13% (30) rural (Figure 2). Phase B represents the period in which the distributor targeted both rural and urban populations and undertook aggressive sales and marketing exercises such as running local promotions and signing up local sales agents. This phase resulted in an exponential growth in customers from 231 to 1376 in which 76% (754) were rural customers and 24% (241) were urban. The exponential increase in sales demonstrates a strong willingness to adopt the SHS – particularly in rural areas. Phase C represents the period in which the distributor temporarily halted promotional events as the team began to focus on customer service issues – only 151 customers were added during this phase (Figure 2).

In order to understand whether customers demonstrated consistent utilization rates over an extended period of time, the percentage of functional units was plotted over time (Figure 3). The results demonstrated a significant drop in customer utilization of the SHSs during the period between December 2013 and April 2014.

The issue of defaulting became pronounced during January 2014 whereby the percentage of functional (non-defaulting) units dropped dramatically from 90% to 40% over the period of 10 weeks (Figure 3). Since a defaulter is classed as being out of credit for four weeks, this indicates that the source of this issue began at the beginning of January 2014. The percentage of customers defaulting over 12 weeks was also plotted over time to determine whether this problem continued to worsen. The percentage of 12 week defaulters dropped at the same gradient as the 4 week, with an 8 week lag time between the two suggesting that this issue was systemic since the beginning of December, 2013, with no sign of improvement.

The rapid rise in defaulting customers coincides with the distributor undertaking promotional activities in November 2013. The sales period for Phase A ran from March, 2013, to the beginning of November, 2013. During this stage the distributor sold units directly to customers from their shop and had sufficient resources to cope with customer relations. The sales period for Phase B ran from November 2013 to April, 2014, whereby the distributor adopted and trained a large number of independent sales agents to sell the units and scratchcards alongside promotional events. The relative success of long-term customer adoption for each phase was measured by plotting the customers' likelihood to default based on the first 12 weeks of usage. Only units installed on or before the 24th January, 2014, could be analyzed and thus Phase C likelihood of default could not be analyzed.

Regression bivariate analysis was applied to determine the probability of default for each phase. It was evident that Phase A, which only acquired urban customers using the shop as a point of sale had a significantly lower probability of default compared to Phase B which made use of sales agents or promotional events, particularly in rural regions (Figure 4). However, the difference in probability of default narrowed the longer the customer had remained in credit for the first 12 weeks after install.

There were a total of 111 customer complaints logged over the period of February-May 2014. Over 80% of the complaints were linked to issues with incorrect installation of the unit. Many of these faults were addressed and dealt with by the distributor within the period of a week and the units had passed the lighting global standards and therefore may be assumed to be technically robust. The total technical failures only made up 1/7th of defaulting customers and many of the issues appeared to be resolved quickly and therefore the explanation for large scale and sustained default may not be attributed to technical failure of the systems.

5.2. Attributes of the Innovations

5.2.1. Customers

Customers that had defaulted for more than eight weeks up to the 13 May 2014 were interviewed in order to gain a general understanding of reasons for long-term default. Only selecting defaulters of greater than 8 weeks increased the chances of interviewing customers who were more likely to permanently default. In total, 16 rural and 11 urban customers were interviewed, of which 24 were male and 3 were female. All of the respondents were between the ages of 20 and 34, except for one who was between 45 and 49. Income sources of respondents were not collected.

When asked to provide the main reason for adopting the PAYG SHS, approximately half the respondents identified both lighting and phone charging as their main reason[1] for adopting the unit

[1] Respondents could pick more than one reason

(Figure 5). A quarter of these stated that they did not have to spend time and money buying kerosene or pay someone else to charge their phone. Approximately half of the survey respondents stated that their main reason for purchasing the SHS was because it offers the ability to charge their mobile phones. There was no correlation between responses and whether a customer was rural- or urban-based, however this may be, in part, due to the small sample size. This finding correlates with a recent GIZ paper on customer preference for mobile charging enabled Pico-PV power technologies (GIZ, 2012). The SHS as a technology therefore appears to offer satisfactory compatibility with the existing customers' lifestyle by providing the key services of lighting and charging.

With regard to the reason for defaulting, more than 75% of the respondents claimed to default for one or more of three main reasons: (i) a lack of money at a particular time of year; (ii) they were travelling; or (iii) their system needed repair or had been stolen and they had not reported it to the distributor. Less frequently mentioned reasons included that they were not aware that they had to top-up regularly; or the husband would place the responsibility of topping up the system solely on the wife, by doing this, the husband felt justified in wanting to keep the unit during repossession as he was 'not at fault'.

Direct observation of the customer agreement process confirmed that before the leasing contract was signed by the customer, the distributor undertook a strict procedure when outlining the terms and conditions of unit reclamation due to default including when they will receive warnings, how they can prevent reclamation and how and at what time reclamation would occur. Furthermore, one week before a customer was at risk of defaulting they would receive a phone call from the distributor to inform them of this risk and that the unit is likely to be reclaimed if they default.

When defaulting customers were asked if they understood the terms and conditions of unit reclamation for defaulters, only 18 of the 27 survey respondents admitted to being aware of them. Four respondents refused to answer the question. Approximately a third of those interviewed accepted the terms and conditions but refused to return the unit claiming that they had full ownership of the unit. It was common for the respondent to become highly agitated, and in some cases aggressive, when the sales agents attempted to repossesses the unit, making repossession challenging. This suggests that rather than being an issue of poor governance by the distributor, the challenge of the PAYG model appears to be a cultural clash with the concept of possession versus ownership.

5.2.2. Cash Flow

Around half of the sales agents interviewed believed that the main reason for customers defaulting was due to customers having no money, especially in the period between April-July, whereby many rural farmers spend the majority of their money on seed for the following season's harvest. In contrast to the compatibility of the technology, the reasons for default highlights the potential incompatibility or inflexibility of the current PAYG model with customers, such as farmers, who do not receive a steady income throughout the year.

5.2.3. Access to Alternative Energy Sources

A rapid rise in defaulting customers was also observed in and around an urban marketplace. Over the period of 6 weeks, 95% of the units had defaulted (Figure 6). After interviewing both the agent and a range of customers, two explanations for default became clear. Firstly, due to the nature of market traders, many moved around the country collecting stock and thus did not have a permanent residence in the city. Secondly, unlike in the rural area, urban customers lived within walking distance to a grid connection. Approximately two thirds of the customers interviewed were legally or illegally connected to the national grid and claimed only to use the SHS when the grid was down. The irregular top-up payments assessed for customers around the market place reflected this.

5.3. Social System: Rural vs. Urban Adoption

An important aspect considered in this paper with respect to understanding the rate of adoption of the SHS is the difference in adoption rates between rural and urban areas. The cumulative adoption profiles were plotted for both (Figure 7 & Figure 8). There are clear differences in the rate of adoption between rural and urban areas irrespective of the age or gender of the customers. A rural village, 20km north of the urban area, demonstrated a rapid adoption to almost 100% coverage over the period one week (Figure 7), whereas a dynamic urban market area in in the centre of the city demonstrated a much slower convex adoption curve (Figure 8). The geographical spread of adoption also varies between both areas irrespective of age or gender, with neighbouring households more likely to adopt in the rural village, compared to a more dispersed adoption in an urban setting (Figure 9 & Figure 10).

5.4. Communication Channels

5.4.1. Promotional Events

A second factor considered when assessing adoption characteristics was the way in which the distributor communicated the concept of the PAYG SHS to potential customers. The distributor used two main communication channels: (i) promotional events combined with local sales agents; and (ii) a shop in the urban centre. Promotional events involved the sales team visiting a specific community for two to three days whereby a community meeting was held to demonstrate and explain the technology. Each event included a stall, unit demos and local live music as well as branded prizes such as t-shirts and caps. People were able to by the units directly from the stall through local sales agents. The unit price was not adjusted. The impact of these events resulted in significantly higher daily unit sales and rural villages demonstrated daily sales that were 2.5 times higher on average compared to promotional events in urban areas (Figure 11). This suggests that promotional events can have a significant impact on the rate of adoption; especially in rural settlements.

6. Discussion

This section applies the diffusion of innovations theory as a framework to analyse the last mile challenges associated with the PAYG SHS. It discusses the strengths and limitations of the PAYG SHS with regard to the innovation adoption attributes, the communication channels used and the social system. The results of which are summarised in Table 3.

6.1. Attributes of the PAYG SHS

Three attributes of the PAYG SHS were assessed for this paper: (i) the compatibility of the PAYG SHS with respect to the day-to-day life of the customers as well as the last mile distributors; (ii) the relative advantage it offers over existing technologies offering the same service; and (iii) the complexity of the PAYG SHS, both in terms of the SHS technology and the PAYG business model.

6.1.1. Compatibility

The compatibility of an innovation relates to the extent to which the innovation is perceived as complimenting traditional cultural values, past experiences, and individual needs (Rogers, 2003). Compatibility is key for all innovations. If an innovation is not easily identifiable as being socially acceptable, diffusion is unlikely to happen. It is common for widespread diffusion to fail simply because the innovation was only slightly different to current practices (Rogers, 2003). The significant rates of adoption during the promotional events suggest that the SHS as a technology is highly compatible with the customer lifestyle and needs, especially with regard to providing the essential services of lighting and mobile phone charging.

This paper, however, raises the concern that although the rate of short-term adoption was rapid for the SHS, there are significant long-term compatibility issues surrounding the PAYG model that need to be addressed in order to ensure sustainable adoption. One of the key long-term issues linked to the compatibility of the SHS is the perception of ownership. The customer has full ownership of the unit only when the equivalent of 105 top-ups are paid off. Several incidences were directly observed whereby customers became aggressive when the unit was being reclaimed even though the customer had not covered 10% of the total cost of the system. The issue, however, was more subtle than the customer simply feeling aggrieved for losing the unit. The majority of the time the customer had genuine belief that they owned the unit because it was in their possession – in some cases for up to 6 months. This raises further questions around the topic of differentiating between possession and ownership, particularly for customers who are accustomed to receiving hand-outs from previous development projects.

6.1.2. Relative Advantage

The relative advantage of the PAYG SHS relates to what extent the customer perceives it as being more advantageous in comparison to the technology or service it supersedes. This includes factors such as improvement in productivity, reduction in costs or the improvement of existing practices (Rogers, 2003). The perceived relative advantage is considered to be the most persuasive of attributes to convince customers to adopt (Rogers, 2003).

The extent of the relative advantage offered by the SHS technology was found to vary significantly based on local external factors. As identified in the customer interviews, the SHS was incompatible with customers who travel for a job, whereby many traders travel to the capital city for periods of up to five or six weeks to source stock and see family. This was the second most common issue surrounding defaulting. When the unit is fully installed it cannot be considered a portable item. In addition to the inability to transport the unit easily, and in the case of this study, customers were unable to top-up their units outside the region as top-up cards had not yet been not distributed there. Hence PAYG SHS face significant challenges in regions with a high mobility of population.

Rural areas witnessed rapid uptake of the PAYG SHS where access to alternative electricity sources such as the electricity grid or diesel generators was severely limited either through geography or lack of finance. Around 93% of the rural population of this region rely on expensive fossil fuels for lighting and cooking services (Eder, 2013). During interviews, customers claimed that kerosene can cost up to USD$1.5 per week and charging a mobile phone three times a week can cost up to USD$0.6 which matches the figures in the paper by Rippey and Nelson (2011) in comparison to USD$1.2 per week for both using the SHS. This equates to households a saving USD$0.9 per week, or USD$47 per year. These cost savings correlate closely with GIZ's estimation of savings produced for solar lamps in Uganda of USD$40 per year - not including the additional savings that the SHS offers for phone charging (GIZ, 2012). However, unlike buying kerosene when needed or when money is available, the PAYG model is disadvantaged in that it requires regular payment from customers with irregular and unpredictable incomes, such as farmers. When asked, all rural customers interviewed stated that a connection to the grid, although favoured over a PAYG system, was prohibitively expensive due to the requirement for a large up-front payment – greater than US$150 in some instances. However, the ease of creating an illegal connection to the grid in urban areas appeared to dampen the relative cost advantage of the PAYG SHS, whereby customers used them as a 'back-up' to the grid. The implications of this finding should be accounted for in any policy aiming to increase the uptake of PAYG SHS in areas with proximity to a grid connection.

In addition to prohibitively expensive grid connection fees, the majority of rural households are unlikely to be presented with the option of grid connection for the next two to three decades. It is estimated that only 26% of the rural population in this study will have access to electricity by 2022. The cost to the Government of achieving this grid expansion is projected to be USD$950 million (Ministry of Energy and Mineral Development, 2013).

Therefore, the cost of achieving 100% rural electrification is likely to run into the multiple billions of dollars. The environmental and social cost of prolonged lack of rural access to electricity will also exacerbate the current social and environmental consequences associated with the burning of traditional fuels for lighting and cooking.

The potentially rapid diffusion of PAYG solar technology, which requires minimal government subsidies, as observed in this study, offers a promising short- to medium-term solution to delivering rural energy until the Government can afford to offer grid connection to 100% of rural households at a connection price that is feasible.

6.1.3. Complexity

The complexity of an innovation relates to the extent to which the innovation is perceived as being difficult to comprehend and use. Studies by Nieuwenhout, *et al.*, (2000) and Hystra (2009) recognize that SHS should be viewed as more complex innovations than more widely available solar technologies such as solar lanterns and single solar panel systems.

This was observed during the field level observations in a number of ways, namely:

(i) The SHS requires a skilled technician with specialist tools to install and maintain the units (Figure 12). The PV panel must be bolted to a metal bracket with theft proof screws and then attached to the top of a thatch roof. The technician must also have an understanding of how best to position the PV panel to maximize solar exposure;
(ii) The majority of customers buy almost all of their products in one-off retail purchases therefore they tend to find the concept of regular and long-term payments difficult to comprehend or are not accustomed to long-term financial planning;
(iii) Misunderstanding about how the system worked was common and tended to be grounded in a lack of technical understanding of how energy transfers from the panel into the battery and how the system is locked until a top-up transaction is completed.

The lack of technical knowledge also meant that many customers found it difficult to conceptualize the fact that if they charged their phones through the day, they will have little energy to switch on the lights at night.

6.2. Social System: Homophily vs. Heterophily

Although one may argue that diffusion in rural areas was faster due to the lack of alternative sources of electricity available in the urban area, the diffusion of innovations theory argues that differences in innovation adoption characteristics may also arise between heterophilous and homophilous social networks (Rogers, *et al.* 2005). Homophilous networks are considered to have a high degree of similarity between individuals. These similarities can include, but are not limited to, beliefs, education and socio-economic status. Heterophilous networks relate to the extent to which individuals attributes differ. Homophilous systems generally accelerate the diffusion process, but they are limited to spreading knowledge within their own network (McPherson, *et al.,* 2001). Therefore, full diffusion can only really occur in networks that display some form of heterophilous attributes (Rogers, *et al.*, 2005).

The rural village discussed in Section 5.3 is typical of a homophilous network. The community has strong cohesion between its members and is a small enough population in which all members know each other intimately. Although it demonstrated the highest rate of adoption of any promotional event, the homophilous nature of the community may have also played a key role in the rapid rates of default.

The urban market area within the centre of the city is typical of a heterophilous network. It is a transient network due to the influence of the busy market. The market place case demonstrated a gradual rate of adoption typical of a heterophilous network whereby diffusion spread between different groups and communities. An additional observation is that there was a far greater geographical spread of adoption compared to the homophilous rural village. These results agree with Rogers (2003) that suggests that if successful diffusion of a SHS innovation is to occur, distributors must attempt to understand and consider the influence that heterophilous and homophilous networks have on the diffusion process. This is an important learning for policy makers with regard to understanding the nuances between facilitating the uptake of PAYG SHS in rural and urban populations.

6.3. Communication Channels: Direct Group Promotion vs. Interpersonal

This section discusses the impact that different communication channels used to promote and sell the SHS had on the customers' (i) initial adoption and (ii) long-term use of the SHS.

Rogers (2003) highlights two main communication channels with which to disseminate information about an innovation to potential customers: (i) direct group promotion; and (ii) interpersonal. In general terms direct group promotion comes from outside the social system, whereas interpersonal channels can be from both inside or outside the social system. Direct group promotion is generally seen to be most important during the knowledge building stage whereas interpersonal channels are most important during the persuasion stage.

The local distributor used both direct group promotion and interpersonal channels to raise customer awareness whereby they held promotional events with a stall, demos and music and they also sold units through local sales agents.

Regular promotion events proved popular and resulted in a high adoption of units (Figure 11), however, this paper has identified that promotional events must be undertaken with caution. By simply holding a promotion event in a village, units can be sold to customers who do not live nearby. Therefore, when they pay the deposit and take the unit, the house may not be where they said it was which makes it very hard to track them down for installation, maintenance or repossession. Due to this increased complexity of a SHS compared to the likes of a solar lantern, which requires no installation nor long-term support, it is essential that sales of the units are overseen by a representative who is familiar with each customer. An additional drawback to the promotional events is that, as identified in the agents' interviews, potential customers hold off buying a full price system in the hope of obtaining a subsidized product in a future promotional event.

The main distributor of the PAYG SHS also used individual sales agents as their interpersonal communication channel. The sales agents tended to be owners of small shops. Their responsibilities included selling units and ensuring existing customers bought scratchcards. Sales agents appeared to moderately improve sales, however, as observed in the interviews, data analysis and observations, using sales agents who were unfamiliar with the PAYG model can lead to a significant and rapid rise of defaulters. The rise in defaulters was directly proportional to the number of sales made from sales agents. The majority of sales agents did not feel it was their responsibility to chase up bad customers and by running a shop, they could not invest time in chasing up and potentially angering customers who may buy other products from them.

Thus, although working through local sales agents works well with alternative solar products such as D-light (D-Light, 2012), it does not appear work for PAYG SHS in the regions studied for this paper. The key reasons being that it requires intimate customer relationships and long-term customer engagement. Therefore, alternative communication channels may be more effective for ensuring rapid but sustainable diffusion.

7. Conclusion and Policy Implications

This paper applies the diffusion of innovations theory as a framework to investigate the 'last mile' challenges encountered when launching a PAYG SHS in a region of Central East Africa.

Solar home systems present a much stronger customer value proposition in comparison to the products they supersede such as kerosene or solar lanterns – as is evidenced by the rapid rates of adoption both in rural and urban areas in this study. By offering the dual service of high quality lighting and mobile phone charging, they save the customer a significant amount of time and money as well as reduce the health and environmental risks associated with kerosene. However, a solar home system is a more complex technology and requires trained staff and tools to correctly install the system as well as maintain it over its lifetime. The results of this study suggest that the most appropriate customers for such a product are those who live in rural communities with low migration rates and little access to alternative energy sources such as the grid. A role of policy may therefore be to support the rollout of PAYG SHS in such areas.

The PAYG service model also offers a number of advantages over existing retail models. By splitting the payment into weekly instalments, customers gain access to a superior product and service for less than the weekly cost of alternative products. Moreover, once all the payments have been completed, the customer assumes ownership of the solar home system and can therefore save up to USD$200 over the lifetime of the solar home system. However, the PAYG model requires a more complex and costly go-to-market strategy, particularly within the context of the 'last mile'. Customer engagement is critical whereby customers need to be: (i) vetted to ensure they can make the regular payments; (ii) trained on how to make weekly payments and chased up when defaulting and (iii) trained on how to use the system and report problems. Furthermore, the sales agents must be appropriately trained in the concept of PAYG as well as the terms and conditions of the customer contract and must have the resources to track, identify and chase up defaulting customers. Rather like microfinance, the PAYG model is also inherently more challenging than a retail model in the need to capture regular customer payment over an extended period (months). Moreover, significant investment is required to make it as easy as possible for customers to: (i) make weekly payments by making scratchcards widely available or offering a mobile money service; and (ii) know when to top up and when they are at risk of defaulting. Finally, some level of flexibility in repossession is likely required to account for periods of the year when a large proportion of the customers have no money for instance after farmers have purchased their seeds for the year.

The PAYG model offers the potential to deliver a disruptive positive impact with regard to increasing access to clean affordable energy for the poor. Both the technology and business model, however, are more complex than current alternatives and therefore require a much more developed go-to-market strategy. The cost of achieving widespread diffusion is therefore higher than corresponding products sold at retail, yet this is balanced by the potential for a much faster rate of adoption.

Further research is required to compare adoption characteristics for differing demographics such as gender, occupation, wealth. Secondly, this paper only investigated the challenges faced diffusing a PAYG SHS in a region in central eastern Africa which displays particular social, economic and geographic characteristics. Further study on the challenges faced in a range of different social environments is required. Finally, this study only investigated the rate of diffusion over the period of a year. Additional studies are required over the longer term to develop a broader understanding of the characteristics of diffusion of PAYG SHS for different categories of adopters, ranging from early adopters to laggards.

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Figures and Tables

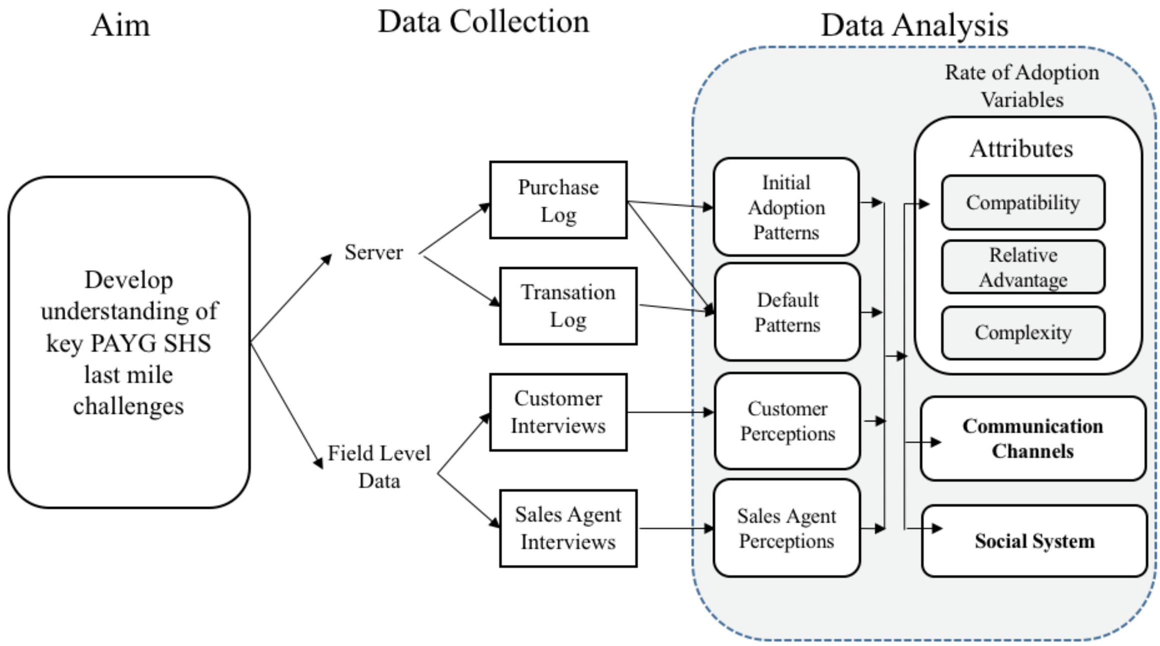
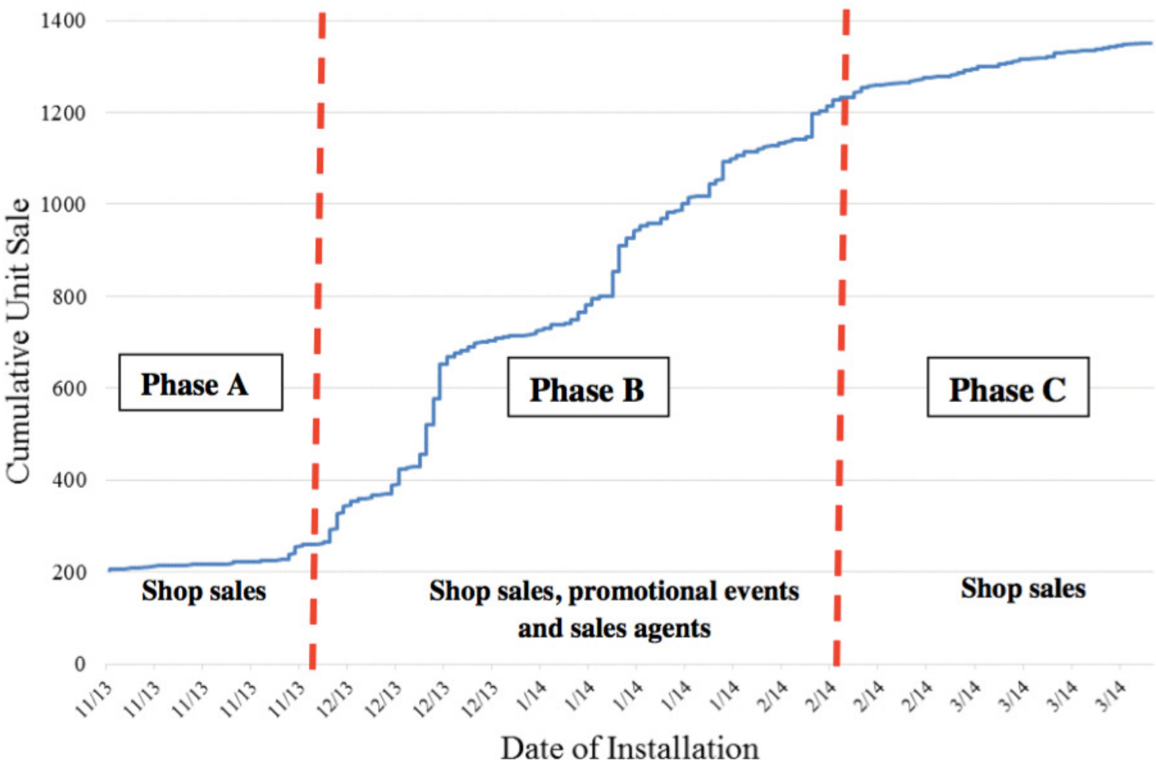


Figure 1: Methodology of study of diffusion of innovation challenges for PAYG SHS in Central East Africa



*The data for this figure was obtained from digital registration logs for 1,352 PAYG SHS between November 2013 and March 2014, the period in which rapid diffusion of the SHS occurred.

Figure 2: Cumulative Sales of all units between 1st November 2013 and 1st March 2014

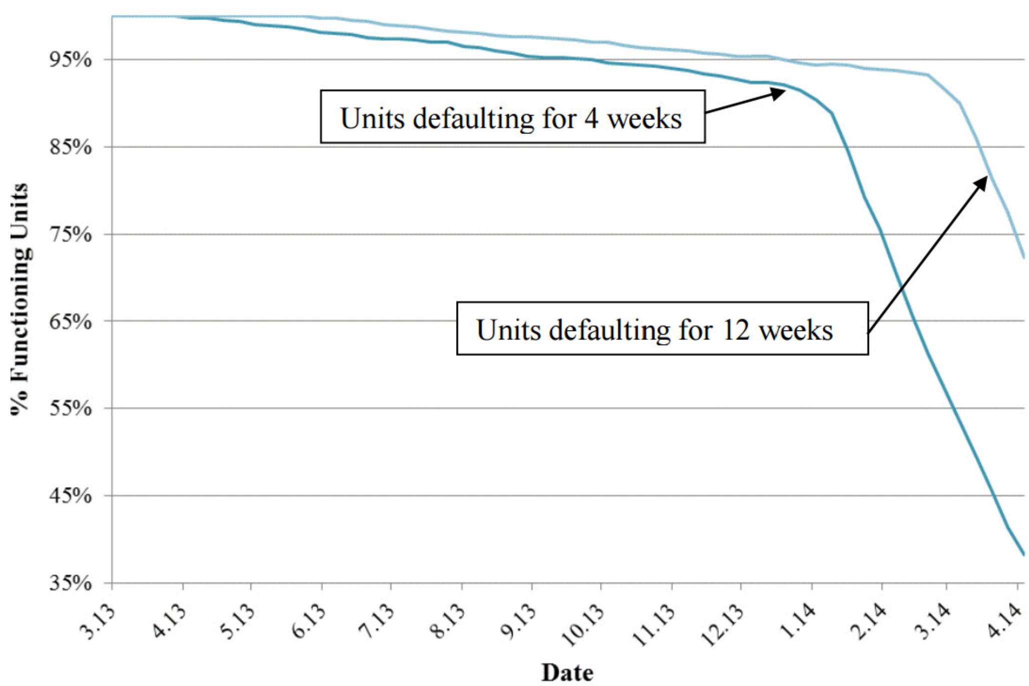


Figure 3: Percentage functioning units between March 2013 and April 2014

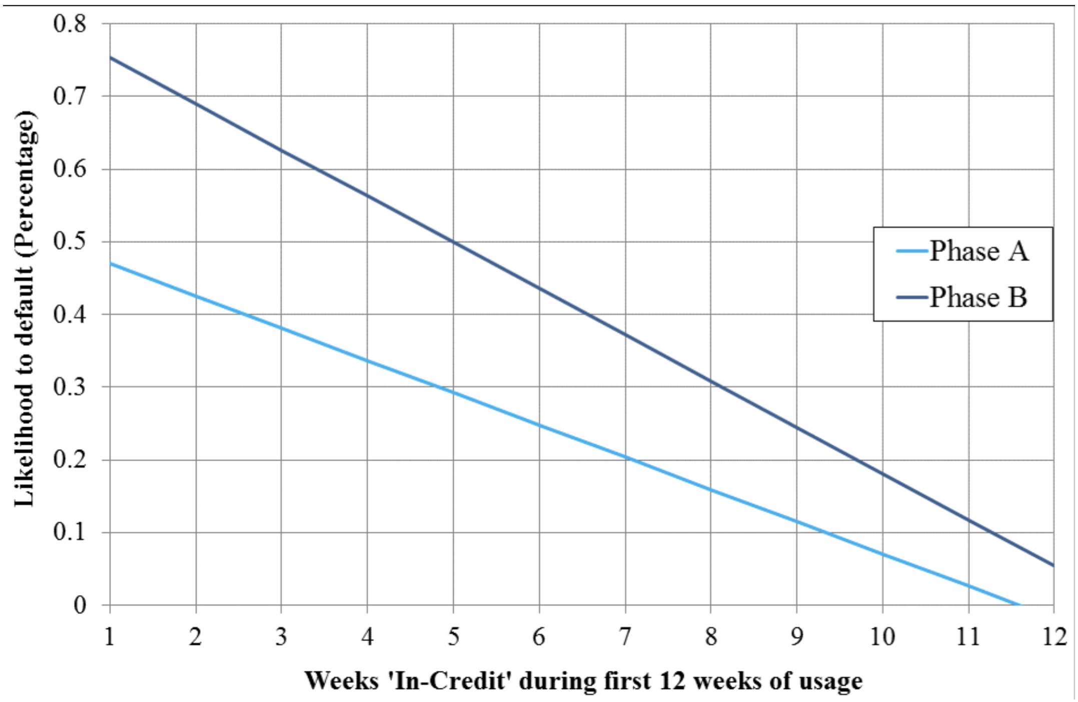


Figure 4: Likelihood to Default Based on First 12 Weeks Usage

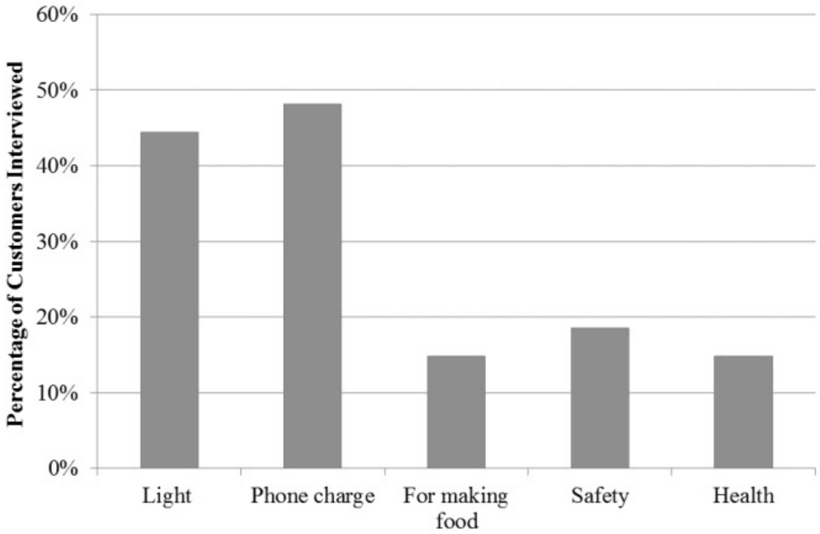


Figure 5: Customer reasons for adopting PAYG SHS

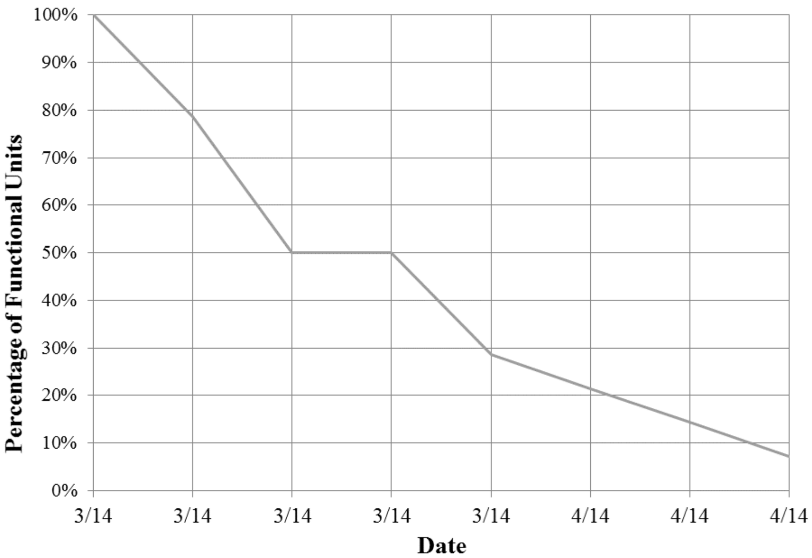


Figure 6: Reduction in functional (non-defaulting) units in the urban marketplace

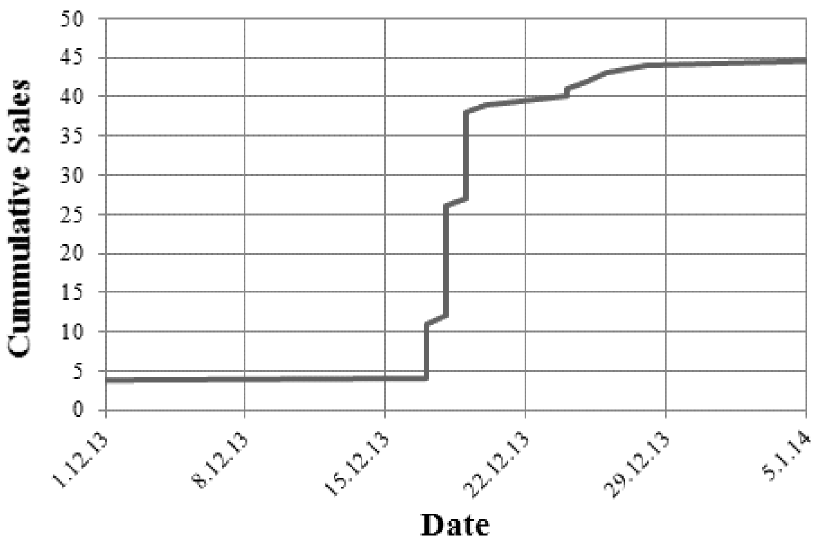


Figure 7: Cumulative unit sales over time for Rural Village

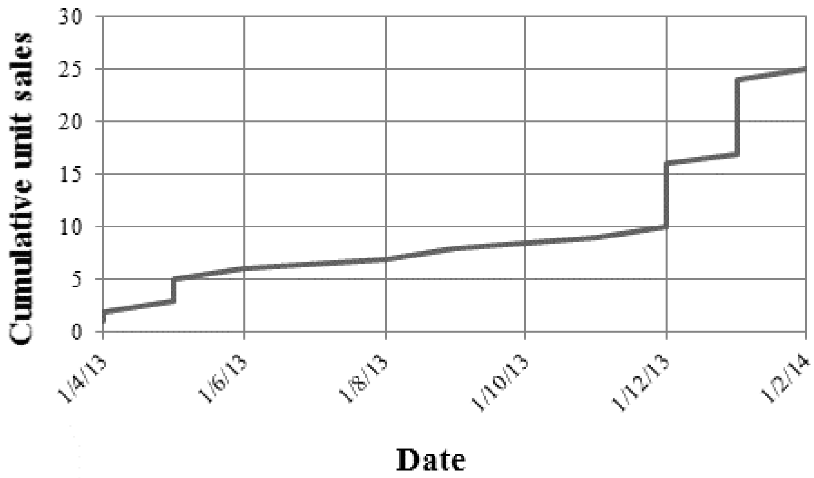


Figure 8: Cumulative sales over time for Urban Area

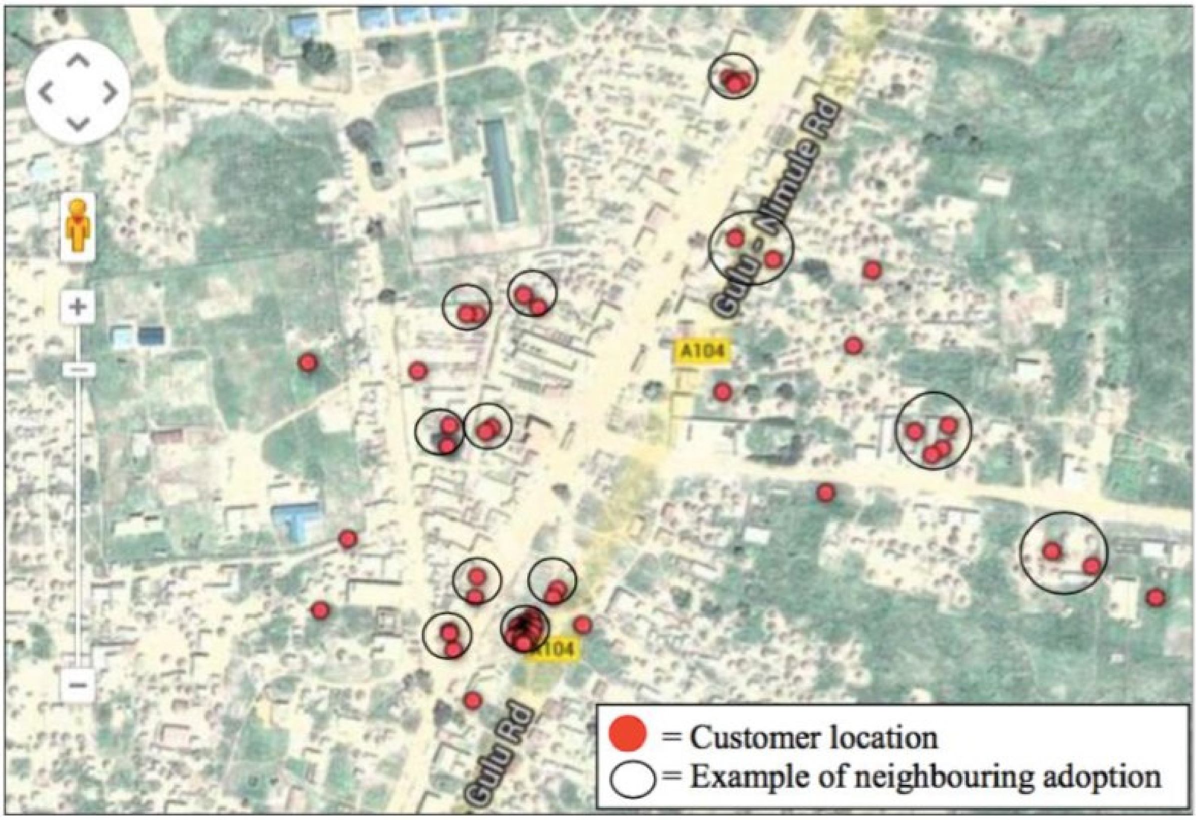


Figure 9: Evidence of high rate of neighbouring adoption of PAYG SHS in rural village (Source: Adapted from Google Fusion Tables, 2014)

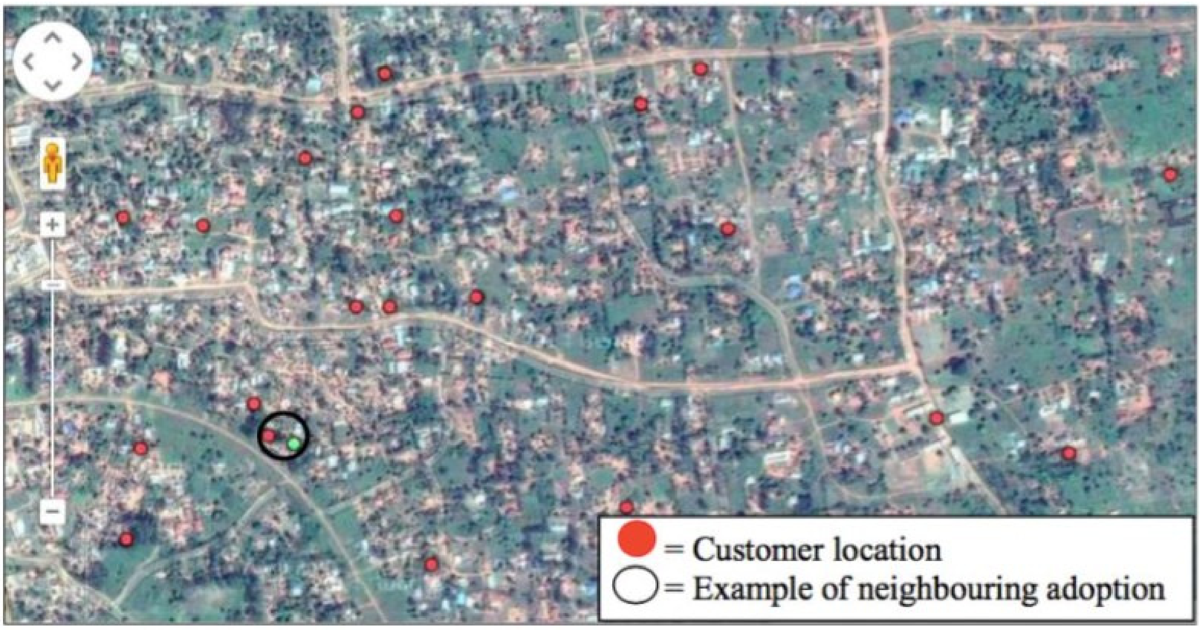


Figure 10: Evidence of low rate of neighbouring adoption of PAYG SHS in urban setting (Source: Adapted from Google Fusion Tables, 2014)

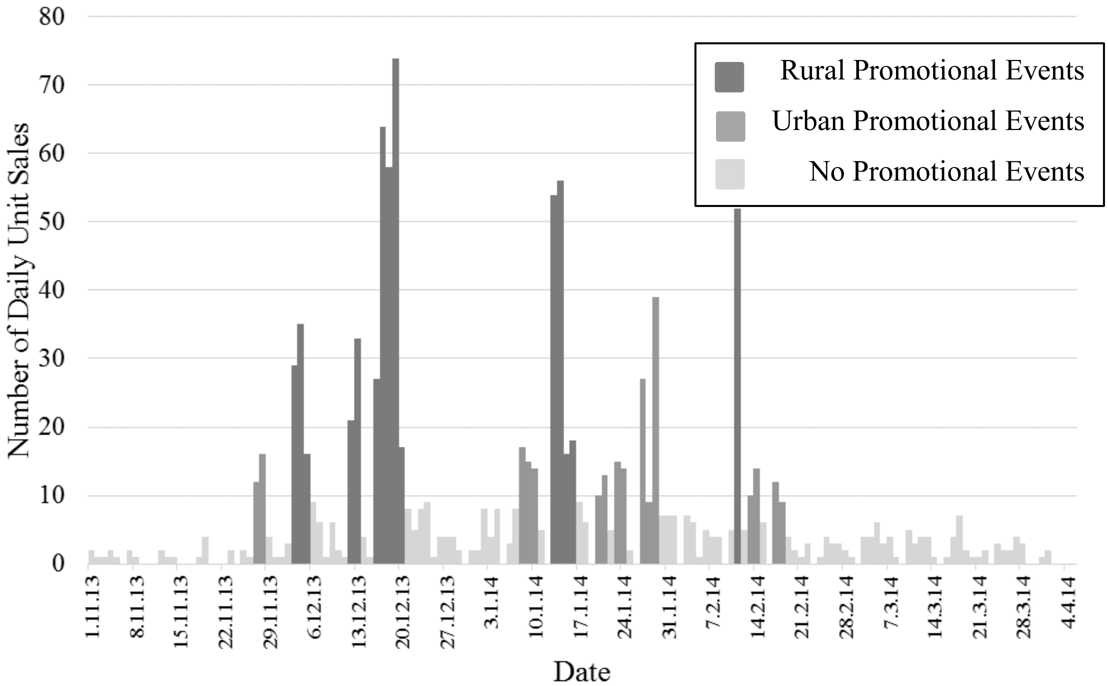


Figure 11: Timeline of number of daily unit sales

Figure 12: Example of SHS Install Complexity and Difficulty

Table 1: Diffusion of innovation variables assessed in this paper

Variable	**Description**
Attributes of Innovation	(i) *Relative advantage:* the advantage a SHS offers in comparison with existing technologies that offer the same service (ii) *Compatibility:* the level of compatibility the SHS has with the day-to-day lifestyles of the customers as well as the standard business models used in the region (iii) *Complexity:* the level of complexity of using and understanding, installing and interacting with the SHS as well as the complexity of method of payment in comparison with existing technologies
Communication Channels	(i) *Direct Group Promotion:* promotional events were the dominant form of communication channel for the PAYG SHS (ii) *Interpersonal:* one-to-one dialogue with customers through local sales agents
Nature of Social System	(i) This paper compares the difference in adoption and long-term usage rates of the PAYG SHS between rural and urban settings

Table 2: Default status analysis methodology example

	Airtime Transactions Per Week						Credit Status Per Week					
Week Number	**23**	**24**	**25**	**26**	**27**	**28**	**23**	**24**	**25**	**26**	**27**	**28**
Serial Number												
1302051	1	0	3	2	1	0	1	0	2	3	3	2
1302052	2	0	0	0	1	3	2	1	0	-1	-1	2
1302053	3	1	1	1	0	1	3	3	3	3	2	2
1302054	2	0	0	0	0	0	2	1	0	-1	-2	-3
1302055	1	0	1	1	2	0	1	0	0	0	1	0
1302056	2	0	0	0	0	1	2	1	0	0	-1	-1

Table 3: Summary of the strengths and limitations of PAYG SHS in a region of Central East Africa

Attributes of Innovation

(i) relative advantage

- SHS offer significant advantages over the use of kerosene for lighting and paying shops for phone charging service. Firstly, it offers the customers a potential saving of USD$47 a year. It saves a significant proportion of time going to an urban centre to charge a phone or buy kerosene. The SHS is much safer than kerosene. Furthermore, the PAYG model allows the customer to own an asset previously unaffordable to them.

(ii) compatibility

- SHS technology is compatible with customer needs in that it provides good quality lighting and easy access to mobile phone charging. However, it is not easily transportable and so causes complication in areas of high net migration.
- The PAYG model is less compatible as it does not fit with a number of local issues such as:
    - Customers tend to use it as a back up to grid supply and so do not make regular top-up payments;
    - Most customers are not familiar with paying for a technology in instalments over the long-term. This leads to confusion over ownership and possession;
    - Finding and training customer service agents to ensure continuous customer engagement is challenging;
    - Income of rural customers fluctuates significantly with the season, meaning therefore, a high risk of defaulting during the growing season, for example.

(iii) complexity

- The SHS as a technology is complex compared to kerosene. Many families did not understand how it fundamentally works and therefore risk draining the battery through the day by charging phones and having no lights for the evening. Furthermore, a high level of training is required to maintenance teams for them to install the system correctly, check for technical breakage and understand where to position the solar panel.
- The PAYG model is complex for customers. They are required to sign a contract to say their

system will be repossessed if they default yet many are illiterate and so fail to understand the meaning of the contract. Secondly, customers who are illiterate often struggle with topping up the system. Customers also found it challenging to maintain regular payments for two reasons, they could not keep track of when they last made a payment and their income fluctuated significantly.

Communication Channels:

(i) *Promotional Events*

- Lead to rapid rates of adoption, particularly in rural areas, however rapid adoption equates to a rapid increase in the need for customer service personnel as well as more thorough customer vetting.
- The areas of rapid adoption appeared to also demonstrate the highest risk of rapid spread of default.

(ii) Interpersonal

- The use of local sales agents leads to low levels of adoption and risk of miscommunication surrounding the PAYG model.
- Local shop owners are unable and unwilling to chase up defaulting customers in fear of losing business.

Nature of Social System: Homophily vs Heterophily

- The difference in social system between rural (homophilous) and urban (heterophilous) settings has a significant impact on the initial adoption and long-term retention of customers.
- Homophilous networks promote rapid knowledge transfer between customers and therefore a subsequent rapid adoption of the SHS.
- Heterophilous networks promote lower levels of knowledge transfer, but higher levels of knowledge transfer between different members of society. Therefore adoption is lower, but offer the ability to diffuse SHS more widely through society.