The diffusion of Solar Home Systems in Rwandan refugee camps

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Abstract

An energy access assessment conducted by Practical Action in 2018 as part of the Renewable Energy for Refugees project established that most households and small enterprises in Kigeme, Gihembe and Nyabiheke refugee camps in Rwanda had limited or no access to electricity. It also identified both demand in the camps for modern energy services and a willingness and ability to pay. To address the lack of access to electricity, two solar home system companies operating in Rwanda were supported by the project to access the camps and supply systems to refugees and the host community via market-based delivery models. This paper applies the diffusion of innovations theory as a framework to investigate the sales of solar home systems in the camps. It is the first paper to present data in this area and it assesses both the viability of market-based delivery of solar home systems in refugee camps and the suitability of using diffusion of innovations theory in these contexts. The results indicate that solar home systems can provide an advantage to households compared to existing energy solutions and are, in most cases, compatible with refugees' basic energy needs and expectations. However, the cost of systems remains a barrier and without subsidy, further reductions in costs or adaptations to payment models, solar home systems are unlikely to provide large proportions of households and small enterprises in the camps with access to energy. This seriously impacts the possibility of achieving Sustainable Development Goal 7 and for the United Nations High Commissioner for Refugees to achieve the objectives it set out in its Clean Energy Challenge policy.

Keywords

Solar Home System; Energy Access; Diffusion of Innovations; Refugee; Humanitarian; Rwanda

Exchange Rate

1 USD = 993.517 RWF

Highlights

- The first study to assess the diffusion of solar home systems in refugee camps
- Explores the delivery of solar homes systems via market-based delivery models
- Refugees can pay for energy by shifting expenditure from other areas
- Solar home systems can help achieve the SDG7 and Clean Energy Challenge targets
- Access to a solar home system was of particular value during COVID-19 lockdowns

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1.0 Introduction

Access to energy is now widely recognised as an essential component of modern life (Jeuland et al., 2021; Nerini et al., 2017) which can support the objectives of other humanitarian sectors including protection (Hastie et al., 2019; Merieau & Egziabher, 2012; Thulstrup & Henry, 2015), education (Dupin, 2018; Moss et al., 2014), health and the environment (Collings & Munyehirwe, 2016; Lahn & Grafham, 2015; Zubi et al., 2019). However, despite its importance, energy is not typically prioritised in humanitarian contexts and most communities rely on unsustainable, unreliable and unsafe forms of energy as a result (Caniato et al., 2017; Grafham & Vianello, 2018; IRENA, 2019; Kyte, 2019; Lahn & Grafham, 2015; Lehne et al., 2016; SE4ALL, 2017). In situations where energy interventions have been made it has often been done in an ad-hoc manner and via free distribution models which have faced issues with their long-term sustainability and been criticised for not meeting community needs (Bellanca, 2014; Cohen & Patel, 2019; Corbyn & Vianello, 2018; Lahn & Grafham, 2015; Oxfam and WFP, 2013; Thulstrup & Joshi, 2017; Whitehouse, 2019).

However, there is increasing recognition among policymakers and practitioners of the importance of energy in humanitarian settings which is highlighted by recent policy developments such as the inclusion of displaced people in the Sustainable Energy for All Global Tracking Framework in 2017 (Sovacool, 2013; World Bank, 2017) and via the addition in 2019 of an indicator on refugees for tracking progress towards the Sustainable Development Goals (Nahmias & Baal, 2019; Transforming Our World: The 2030 Agenda for Sustainable Development, 2015). The creation of a Clean Energy Challenge which aims to ensure that all refugee and host community households have Tier 2 electricity access by 2030 (UNHCR, 2019a) also demonstrates the aspiration to ensure refugee and the surrounding host communities have access to modern energy services. Tier 2 equates to all households having access to at least 50W of power or 200Wh per day of electricity that can provide lighting, air circulation, television and phone charging services for a minimum of 4 hours during the day and 2 hours in the evening (ESMAP, 2015). However, providing Tier 2 levels of energy access to approximately 20 million refugees[1] in less than ten years is a significant challenge that will not occur without direct intervention.

Solar home systems (SHS) (discussed further in section 3.0) can typically meet Tier 2 requirements and are now regularly suggested as a way of improving energy access levels in refugee camps (Abdul-Salam & Phimister, 2019; Bertheau, 2020; Narayan et al., 2019; Quak, 2018; Yadav et al., 2019). However, there are challenges regarding the affordability of systems that prevent SHS diffusion in humanitarian contexts. For example, the high upfront cost means purchasing a system outright is impossible for most refugee households. Furthermore, refugee households often have variable incomes, making it difficult for them to commit to regular payments. This challenge is further compounded by the uncertainty many refugees face regarding resettlement and the restrictions on their right to work or access to income-generating opportunities. These affordability challenges are further exacerbated by the fact that many private sector companies view refugee customers as high risk and because humanitarian agencies do not typically have funding to subsidise energy technologies or to support private companies (Corbyn &

[1] At the time of writing there were 20.4 million refugees under UNHCR's mandate (excluding Palestinian refugees). No reliable data could be found to calculate the number of people living in the host communities.

Vianello, 2018; D'Annunzio et al., 2016; Gerrard, 2016; Grafham et al., 2016; Lahn & Grafham, 2015; Lehne et al., 2016; Lyytinen, 2009; Thulstrup & Joshi, 2017).

The provision of SHS via market-based delivery models[2] has been suggested as a way of addressing both the affordability challenges faced and as a way of mitigating issues regarding long-term sustainability present in the current system (Boodhna et al., 2019; Corbyn & Vianello, 2018; Patel & Gross, 2019; Practical Action, 2019; Rosenberg-Jansen, 2018; Van Landeghem, 2016; Whitehouse, 2019). This also fits into a broader shift in the humanitarian sector to address refugee needs via market-based approaches (Betts et al., 2016; Doocy & Tappis, 2017). In particular, Pay-As-You-Go (PAYG) is viewed as one of the most promising delivery models because it allows the end-user to pay for the system in instalments over a period of time (Barrie & Cruickshank, 2017; Muchunku et al., 2018; Yadav et al., 2019). However, purchasing a SHS in this way still represents a long-term financial commitment compared to traditional energy sources, which can be purchased or not depending on income constraints (Baurzhan & Jenkins, 2016; Mondal & Klein, 2011). This difference may not be compatible with many refugee households' variable incomes in the long term without business model adaptations.

Although there is a significant amount of literature on energy access delivery models (Friebe et al., 2013; Lay et al., 2013; Rolffs et al., 2015) there has been limited research on the challenges of diffusing these technologies (Barrie & Cruickshank, 2017). Furthermore, existing research suggests that the diffusion of SHS does not automatically result in providing sustainable and lasting renewable energy access (Turner, 2019) and evidence suggests that in the past few SHS interventions have been successful (Holtorf et al., 2015a). For example, previous humanitarian energy projects in Kenya (Okello, 2016; Whitehouse, 2019) and Burkina Faso (Corbyn & Vianello, 2018) have not achieved high diffusion levels. Authors such as Amuzu-Sefordzi *et al.*, (2018) and Kizilcec and Parikh (2020) have also recommended that a better understanding of the factors influencing the slow adoption and subsequent diffusion of SHS is crucial and that more research is required on context-specific challenges to diffusion.

This paper aims to evaluate PAYG SHS's diffusion in Kigeme, Nyabiheke and Gihembe refugee camps in Rwanda and to discuss the implications the findings have for achieving policy objectives such as SDG7 and the Clean Energy Challenge. This is achieved using a 'diffusion of innovation' framework, which was developed to evaluate how effectively new technologies spread once they enter a market. The analysis is based on data collected by the Renewable Energy for Refugees (RE4R) project, which supported the Rwandan companies (BBOXX and BELECOM) to provide the SHS to refugees and the surrounding host community (discussed further in section 3.0).

2.0 Kigeme, Nyabiheke and Gihembe Camps

This paper's focus is three refugee camps in Rwanda that host refugees from the Democratic Republic of the Congo. The camps have previously been studied by Alloush *et al.*, (2017), (Baranda Alonso et al., 2021), (Thomas et al., 2021) and as part of the RE4R project by Sandwell *et al.*, (2020) and (Practical Action, 2020). The findings of these studies demonstrate that the camps have similar levels of household income and levels of employment. However, some distinct differences could impact the diffusion of SHS.

[2] Market-based delivery models are defined as models in which end-users make a financial contribution towards an energy technology or energy service.

For example, at the time of the survey, household income was highest in Gihembe, but Kigeme and Nyabiheke have more non-agricultural businesses, such as small retailers, that could benefit from a SHS. All the camps use a cash-based transfer and voucher system, which provides refugees with funding to purchase essential goods and services. This system aims to give refugee households greater autonomy over purchasing decisions. A summary of the camps is provided in Table 1 and Figure 1 shows the approximate location of the camps and Kigali, the capital city of Rwanda.

Camp	Gihembe	Kigeme	Nyabiheke
Households	2,910	3,998	2,787
People	12,391	22,950	14,289
Average number of people per household	4	6	5
Total household monthly income[1] (RWF)	83,211	43,113	23,782
Total household monthly income (US$)	83.75	43.39	23.93
Households with wage earner in last 12 months (%)	34	42	47
Non-farm businesses (% of all businesses)	8	13	17
[1] Includes a monthly allowance of 7,600 RWF (US$7.64) per person per month from the World Food Programme.			

Table 1 - Overview of the locations, size and economies of the three camps. Data from (Alloush et al., 2017; Sandwell et al., 2020; UNHCR, 2019b)

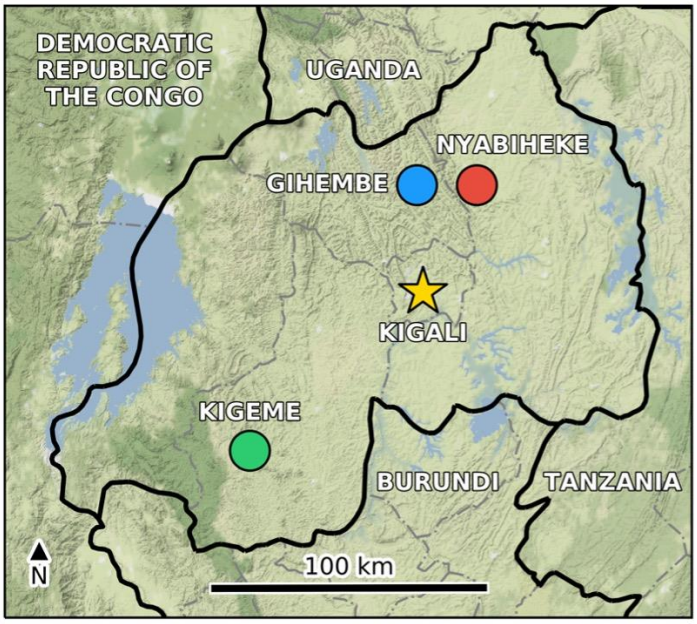

Figure 1 - Map of Rwanda showing the locations of Gihembe (blue), Nyabiheke (red) and Kigeme (green) refugee camps and Kigali, the capital city of Rwanda (yellow star). Source: Sandwell et al., (2020).

Overall, access to electricity in the camps was limited, and no agency has overall responsibility for energy in the camps. Most households rely on candles, lights on mobile phones and improvised battery torches to meet their lighting needs (Sandwell et al., 2020). Around 21% of households had access to a solar lantern, and 16% had access to a SHS (Sandwell et al., 2020). There were also various small businesses operating within households, including retail shops, phone charging providers, food shops, restaurants, bars, tailors, and hairdressers (Sandwell et al., 2020).

3.0 Solar Home Systems

A typical SHS (Figure 2) comprises a 10 to 100 W_p PV panel, a rechargeable battery, appliances and associated equipment such as wiring, switches, a charge controller and communication equipment. The cost of SHS technology has fallen dramatically thanks to developments in solar photovoltaic (PV) panels, light-emitting diode (LED) lighting technologies and batteries (Bisaga & Parikh, 2018; Laufer & Schäfer, 2011; Nayak et al., 2019; Palit, 2013; Twidell & Weir, 2006; Wamukonya, 2007; Zubi et al., 2018). Depending on the SHS's capacity, a range of low-power appliances such as fans, radios, and televisions can also be supported (Efficiency for Access, 2019; Feron, 2016; Lysen, 2013; Rhaman, 2018).

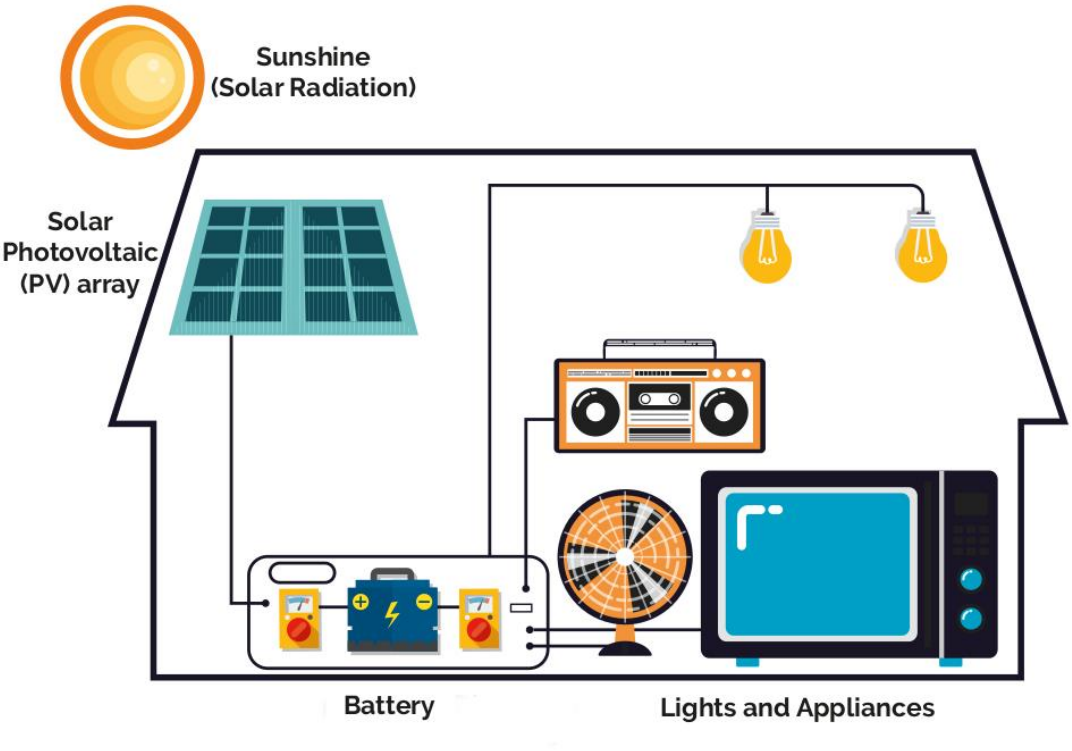

Figure 2 - A simplified schematic showing a typical SHS's main components (authors' own).

Previous research by Thomas et al., (2021) has evaluated SHS technology's appropriateness in Kigeme, Nyabiheke and Gihembe camps via the application of a political, economic, social, technical, legal and environmental (PESTLE) analysis. An overview of the SHS provided by the suppliers supported by the RE4R project and analysed as part of this analysis is provided in Table 2 below.

SHS Model	Financial Details	Key Specification
BELECOM[1]	36 monthly payments of 2,600 RWF (US$2.60) with no direct subsidy provided by the RE4R project. The customer owns the SHS at the end of the agreement.	12W, 20W and 22W solar module[2] 7Ah battery 2 x USB ports for charging 3 x LED lights (maximum 5) Includes a radio 3-year warranty

BBOXX bPower50[2,3]	36 monthly payments of 2,900 RWF (US$2.90) which includes a subsidy of 2,000 RWF (US$2.00) provided by the RE4R project. The customer owns the SHS at the end of the agreement with an option to continue paying 2,900 RWF (US$2.90) per month to receive an extended warranty and customer support.	49W solar module 17Ah battery 2 x USB ports for charging 3 x LED lights (maximum 6) Can connect additional devices made by BBOXX for an extra fee, including a radio, TV, shaver and speaker system 3-year warranty (plus the option to extend)
[1] Unpublished information provided by BELECOM to the RE4R project [2] BELECOM systems initially had a 12W solar module, but following customer feedback, the module was upgraded to a 20W module**.** Existing customers received an additional 10W module. This resulted in three systems sizes. [3] https://www.bboxx.com/products/bpower50/ [4] https://data.verasol.org/products/sek/bb-home?viewall=true		

Table 2 - Overview of SHS provide as part of the RE4R project

4.0 Diffusion of Innovations Theory

Diffusion of innovations theory is an established framework that can be used to investigate the way technologies spread (Rogers, 2003). The approach involves the analysis of five factors that have been shown to be key drivers in how quickly technologies are adopted. According to Sommerfeld, Buys and Vine (2017), the theory is valuable for policy development because it can be used to assess the factors that impact levels of adoption, help to understand the decision-making process of adopters and can also be used to evaluate whether an innovation is consistent with socio-cultural values. This paper investigates three of the five main areas identified by Rogers et al., (2005) that can influence diffusion levels: (1) relative advantage; (2) compatibility; and (3) complexity. It was not possible to include an analysis of the fourth factor (observability) because there were challenges associated with collecting location data in the field and also because there were concerns that refugees may be identified from the data presented. The fifth factor (trialability) is also not included in this analysis because end-users could not trial SHS as part of the RE4R project. This is not considered to impact the validity of the findings because these two factors are not as influential as the other attributes (Barrie & Cruickshank, 2017; Rogers, 2003). However, this analysis does include communication because it can significantly impact adoption (Barrie & Cruickshank, 2017; Holtorf et al., 2015a). An overview and description of the attributes assessed as part of this study are provided in Table 3.

Attribute	Description
Relative Advantage	The advantage a SHS offers compared to an existing solution for issues such as livelihoods, health, comfort, convenience and safety.
Compatibility	How compatible a SHS and the delivery model is with the day-to-day lives, values, past experiences and needs of adopters.
Complexity	How well end-users understand the delivery model and how easily they can operate and maintain systems.

Communication	How adopters find out information and the impact of sales events and sales agents on the diffusion process.

Table 3 – Overview of the key attributes assessed as part of this study, *based on Barrie and Cruickshank (2017) and Amuzu-Sefordzi et al. (2018)*.

The research builds on several existing studies that have explored the diffusion of SHS (Barrie & Cruickshank, 2017; Holtorf et al., 2015a; McEachern & Hanson, 2008; Opiyo, 2019; Turner, 2019) and diffusion in refugee camps (Clarkson Mvo & Tidze, 2018; Heaslip et al., 2018; Marinakis et al., 2016). However, this is the first investigation of SHS diffusion in refugee camps.

5.0 Methodology

The research uses data collected in collaboration with the RE4R project from three sources: (1) supplier sales reports; (2) customer monitoring surveys; and (3) field observations. It is important to note that the primary purpose of the data collected was to inform RE4R monitoring, evaluation and learning activities and not specifically to assess diffusion. The survey was designed collaboratively to ensure validity; however, there were some limitations on the questions that could be asked and the surveys' timing. These limitations are outweighed by the benefits of repurposing the data in this way which include access to a much large dataset than would have otherwise been possible and because it also helps to reduce beneficiary fatigue which is often a challenge in these contexts. The data used was collected over 12 months from the sale of the first SHS in July 2019. An overview of the research process is provided in Figure 3 below.

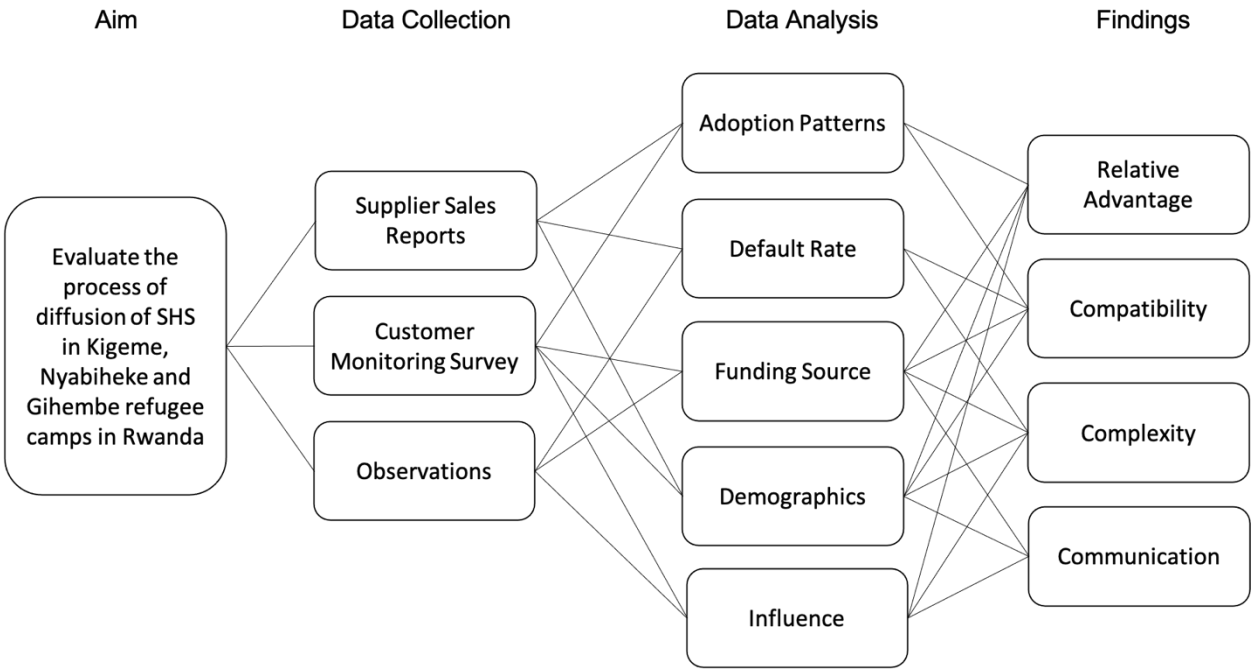

Figure 3 - Overview of the methodology used to evaluate the diffusion of SHS in Rwandan refugee camps.

5.1 Supplier Sales Reports

The supplier sales reports were submitted monthly by BBOXX and BELECOM to the RE4R project. The reports track the number of SHS sales made in each camp. They include basic customer demographic data (e.g., customer gender and household size), the type of system acquired, the date of contract and date of installation, the customer employment status and whether a customer has delayed payment, defaulted[3] or had their system repossessed. In total, the reports recorded the sales of 1,515 BBOXX and 1,587 BELECOM SHS between July 2019 and July 2020. This data is used in this paper to track the daily and cumulative adoption patterns of different SHS in each camp. The number of SHS adopted per month is calculated based on the install date recorded in the supplier sales report and plotted over time for each camp on a monthly and cumulative basis. The supplier sales report data is also used to analyse the impact employment status and household size has on sales. An evaluation of the default and repossession rate is also made using this data and compared between SHS size and gender of the customer.

5.2 Customer Outcome Monitoring Survey

Outcome monitoring surveys of customers that had acquired a SHS from a RE4R supplier were conducted by Practical Action in September 2019 and December 2019. The surveys were conducted in Kinyarwanda, a widely spoken language in the camps, and the responses were recorded in English electronically on a tablet. The first section of the survey recorded household information, including the household's approximate location, household composition, and information on the head of the household. The second section recorded information on the SHS, including the supplier the respondent selected, the appliances they are using, their motivation for purchasing the SHS, their knowledge of the payment system and their satisfaction with the system. The survey primarily collected quantitative data, and where qualitative data was collected, it was typically from a list of pre-determined options. However, participants were also allowed to select other reasons if they did not fit within one of the provided options. The final question participants were asked was if there was anything else they wanted to share which produced valuable qualitative insights discussed throughout the paper.

5.3 Observations

The supplier monitoring data and customer monitoring surveys are supported by the project field coordinators' observations in the camps. This includes observations of the BBOXX and BELECOM sales and customer services process, conversations the coordinators were having with refugees and the host community, humanitarian agencies in the camps and the SHS suppliers, including the sales agents. Most of the evidence is recorded in unpublished learning logs written by the field coordinators every month during the project. However, observations were also made by the lead author, who was a member of the RE4R Technical Working Group throughout the project and participated in regular workshops associated with the RE4R project, including a decision-making workshop held in Kigali in May 2018 and the contextual review workshop held in Kigali in April 2019. This qualitative observation data's inclusion helps contextualise and validate the primarily quantitative data collected in the supplier sales reports and customer monitoring surveys.

[3] Defined as not having paid after 30 days

5.4 Data Cleaning and Limitations

There were some validation errors in the data, particularly the suppliers' data, that were corrected after the data was collected. Some of these errors were easily corrected, such as where the camp name had been misspelt or errors regarding how dates had been recorded. For example, some sales dates were recorded in the United States format (i.e., MM/DD/YYYY), suggesting sales were made before the project started. There were also records where the installation or contract dates recorded were incorrect. In most of these cases, a comparison could be made between the installation and contract date to estimate an accurate date. However, in 17 BELECOM entries (1.06% of the total number of records) the date of installation and contract were both before the project started, and it was not possible to confirm an accurate date of installation. These data entries were removed as a result.

There were also some issues and inconsistencies with the way BBOXX data was collected towards the end of the project. This meant that the final dataset had 210 records that were missing information on household size and the customer's employment status. As a result, the data presented for this section of analysis only covers the 87% of BBOXX customers where this data was collected. There were also some inconsistencies with the way BBOXX and BELECOM reported customer employment status. For example, the BELECOM data indicated that 24-28% of households in Nyabiheke and Gihembe were unemployed, and 0% were keeping house or raising children. The same data for Kigeme camp suggested 0% were unemployed and were 29% keeping house or raising children. According to the BBOXX data, 0% of households were keeping house or raising children in any of the camps. A comparison was then made between the supplier sales report data and the data collected as part of the customer monitoring survey, which asked the respondent's main occupation over the last 12 months. This data suggested that in Gihembe and Nyabiheke, approximately 30% of households were keeping house or raising children full-time compared to 0% in Kigeme. To overcome this data limitation a decision was made to group records recorded as unemployed with keeping house or raising children and is discussed further in section 6.4C. Other employment status data were also grouped for ease of analysis and presentation. For example, in some cases, such as for 'casual/ day labourer', only one entry was recorded so these responses were grouped with similar employment status such as 'employee receiving wage/ incentive worker'. Similar adjustments were made to the customer monitoring survey data. For example, one entry related to how the customer had paid for the SHS had been recorded as 'Other (got money for the job I did)' which was updated to 'Casual work'.

5.6 COVID-19

There were several challenges associated with COVID-19 lockdowns in Rwanda that impacted the collection and analysis of the data presented. For example, SHS sales and after-sales support were impacted as the SHS shops were forced to close. There were also disruptions to supply chains and technicians could not access camps. Furthermore, the follow-up customer outcome monitoring surveys and a non-customer survey that was due to be completed in March 2020 and June 2020 were cancelled because of COVID-19 restrictions and are not included in this analysis as a result. COVID-19 also impacted refugee's livelihoods; in particular, their ability to find work was further reduced and increases in the costs of goods and services in local markets added additional pressure to household budgets. The implications of COVID-19 on the findings of this paper are discussed throughout the following sections.

6.0 Data Analysis

6.1 Adoption Patterns

BELECOM started selling SHS in Nyabiheke camp in July 2019, in Gihembe camp in August 2019 and in Kigeme camp in September 2019. Figure 4 shows the monthly and cumulative installations of BELECOM SHS over a 12-month period from the first installation date. In total there were 454 installations in Nyabiheke, 465 in Gihembe and 669 in Kigeme. The graph demonstrates several peaks and troughs in the number of installations carried out. For example, there was a significant drop in the installation of SHS in October (n.16) compared to September (n. 172) and November (n. 248). This was because demand for the BELECOM SHS was higher than anticipated and there was not sufficient stock in Rwanda to fulfil orders in October. There is also a fall in installations in December and January which was when BELECOM stopped selling a 12W system following customer dissatisfaction (see section 7.2 for further discussion) and started offering a 20W system. Sales also fell dramatically in April 2020 due to the lockdown imposed across Rwanda associated with Covid-19.

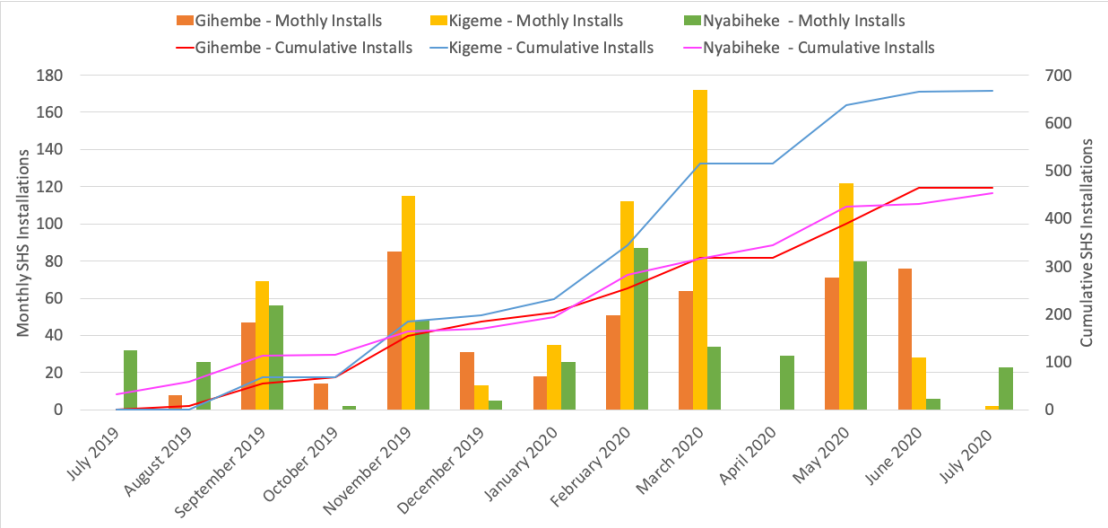

Figure 4 - Monthly and Cumulative sales of BELECOM SHS in Gihembe, Nyabiheke and Kigeme camps

In comparison to BELECOM, BBOXX started selling their SHS in all three camps at the same time. Figure 5 shows the monthly and cumulative installations of BBOXX SHS over the same 12 month period. In total there were 486 installations in Gihembe, 603 in Kigeme and 426 in Nyabiheke. Monthly installations peaked in August 2019 when 254 SHS were installed in Kigeme. However, SHS installations fell once BBOXX reached its quota of SHS that were subsidised with funding from the RE4R project. As a result, the number of recorded sales between October 2019 and July 2020 was just 59.

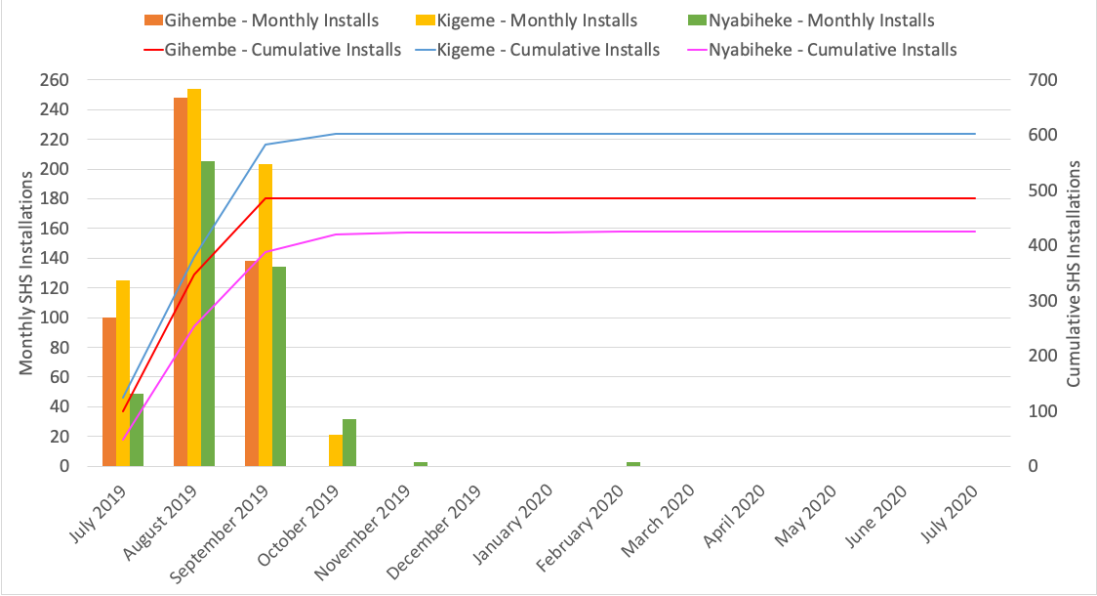

Figure 5 - Monthly and Cumulative sales of BBOXX SHS in Gihembe, Nyabiheke and Kigeme camps

6.2 Funding Behaviour

Most customers funded the monthly payment for their SHS through their cash-based transfer (79% for BELECOM and 66% for BBOXX). Figure 6 shows the primary funding source for BELECOM customers (left pie chart) and BBOXX customers (right pie chart). A more significant proportion of BBOXX customers (27% vs 12%) funded the monthly payments for their system through regular income from a business or occupation and BBOXX customers were also more likely (17% vs 12%) to indicate that more than one funding source was needed to cover the cost of purchasing a system. BBOXX customers also funded their monthly payments from a wider range of sources, such as savings groups or by borrowing money from friends compared to BELECOM customers.

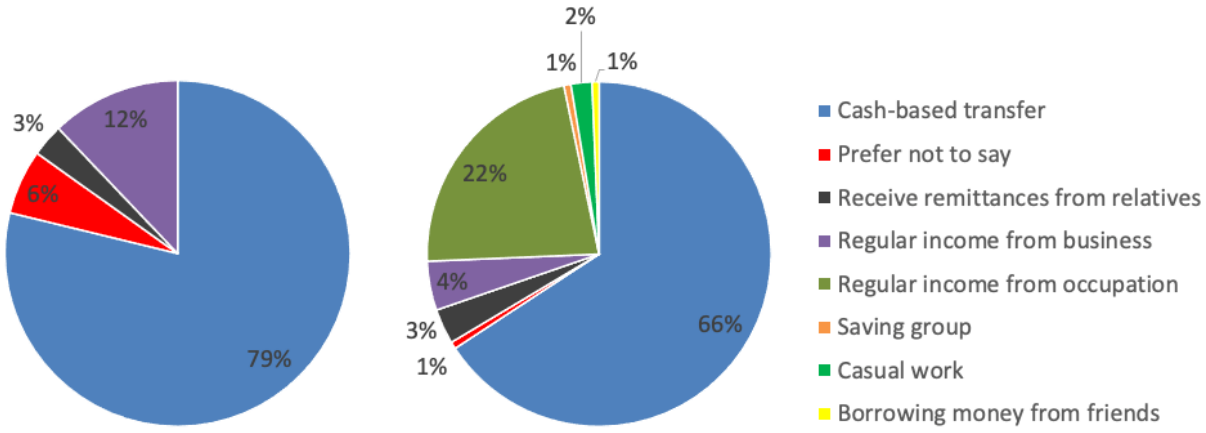

Figure 6 - Primary source of funding for SHS monthly payments for BELECOM (left) and BBOX (right) customers

Customers were also asked whether they had to make any changes to their expenditure to make the SHS payments on time (Figure 7). The data indicates that BBOXX (right pie chart) and BELECOM (left pie chart) customers' behaviour is similar and demonstrates that over 75% of SHS customers needed to either reduce expenditure or increase income in at least one area. The most common way recorded was by reducing expenditure on food (38% BELECOM and 41% BBOXX) and a significant proportion of customers (13% BBOXX and 8% BELECOM) also reduced expenditure on other basic needs such as clothing. The survey data did not quantify the reductions in spending and it is also important to note that reduced expenditure on basic needs may have included previous energy expenditure such as candles and mobile phone charging which the SHS replaced. A more significant proportion of BELECOM customers (10% vs 4%) preferred not to state whether they had to make changes to afford a SHS.

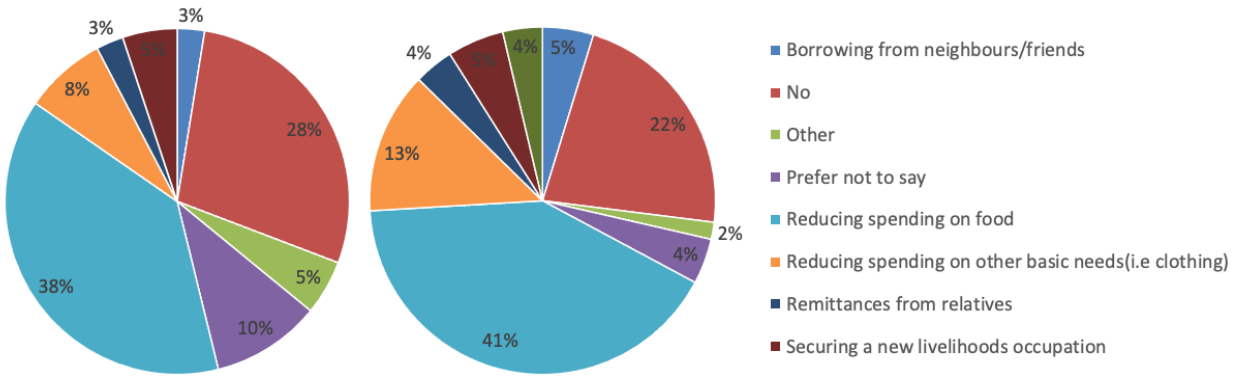

Figure 7 - Expenditure changes made by BELECOM (left) and BBOX (right) customers to afford a SHS

Customers were able to accurately describe that they were paying in instalments for their SHS, indicating that they understood the payment model. Only 1 out of 185 respondents described their payment method as an upfront payment. However, a wide range of responses were given when customers were asked how many payments they needed to make for their system. Table 4 provides an overview of this data and demonstrates that 54% of BBOXX customers and 58% of BELECOM customers correctly identified that the payment term for the SHS that they had purchased acquired was 36 months. It is important to note that BBOXX customers who identified their payment term as 48 or 60 months could have been basing their answer on their ability to continue payments beyond the initial term to continue receiving warranty and customer support.

	12 months	24 months	36 months	48 months	60 months
BBOXX	14%	20%	54%	11%	1%
BELECOM	33%	9%	58%	0%	0%

Table 4 – Survey respondents understating of the payment term for each SHS supplier. The correct standard term is highlighted in green.

6.3 Influence

Customers were asked who or what motivated them to acquire a SHS as part of the customer monitoring survey. They could select more than one reason from a list of options and could choose their

own motivation if required. Figure 8 breaks the influencer down by the first, second, third and fourth most influential motivations provided by customers. It demonstrates that sales agents were the most influential reason for customers to adopt a SHS, although neighbours, friends and family, and events and a desire for the product/service are important primary motivations. Events were not stated as a primary motivation for acquiring a SHS but were often cited as a secondary or tertiary motivation. Of least importance at all stages were opinion leaders in the camps. Some respondents provide other motivations including that they wanted to reduce expenditure and time spent charging mobiles away from the home and purchasing candles or that they wanted to enable their children to study after dark. There were only minor differences between BBOXX and BELECOM customers identified in the data. For example, BBOXX customers were more like to be influenced by an event and BELECOM customers were more likely to be influenced by a sales agent who were employed by the suppliers from the refugee population. It is also worth noting that no BELECOM customers selected more than one reason why they were influenced in comparison to BBOXX customers who in some cases provide four reasons

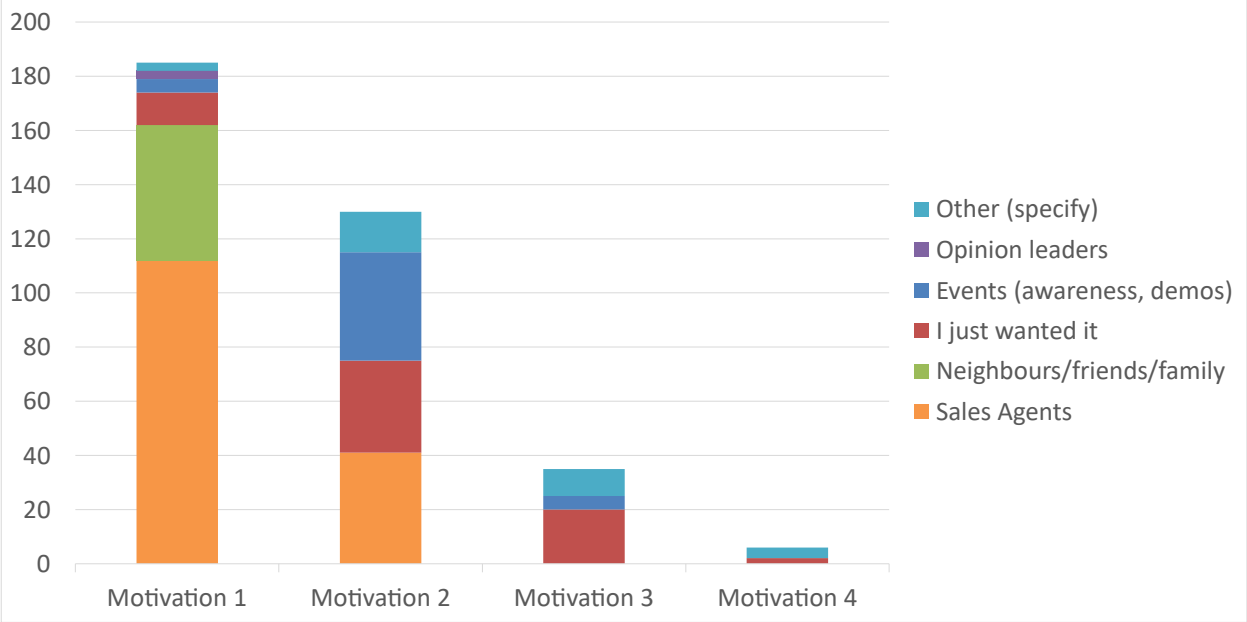

Figure 8 – Number of respondents who stated certain stakeholder influenced them to acquire a SHS ranked in the order given for BBOXX and BELECOM across the three camps.

6.4 Customer Demographics

6.4.1 Gender

Table 5 demonstrates that women were the customer for most BELECOM SHS and that there is little discrepancy based on the size of the system. It also demonstrates that in Kigeme the percentage of female customers is significantly higher than in Gihembe and Nyabiheke. In comparison, there was a more even split between male and female BBOXX customers and little discrepancy between camps (Table 6).

	Gihembe				Kigeme			Nyabiheke			
	12W	20W	22W	Total	12W	20W	Total	12W	20W	22W	Total

Male	37%	34%	35%	35%	7%	11%	10%	33%	28%	19%	23%
Female	63%	66%	65%	65%	93%	89%	90%	67%	72%	81%	72%

Table 5 - Breakdown of BELECOM customers by camp, system size and gender

	Gihembe	Kigeme	Nyabiheke
Male	56%	46%	58%
Female	44%	54%	42%

Table 6 - Breakdown of BBOXX customer by camp and gender

6.4.2 Household Size

There was a wide range of household sizes that acquired a BELECOM or BBOXX SHS. The majority of households comprised 3-9 members. For example, 85% of BELECOM customers and 89% of BBOXX fell within this range. This is in line with the average household size. For example, 82% of households across the camps comprise 3-9 members. The largest BELECOM households comprised 15 members (n. 1 in Gihembe and n.2 in Kigeme) and the largest BBOXX household comprised 12 members (n. 1 Kigeme and n. 1 in Nyabiheke). The smallest households for both suppliers and in all three camps comprised of 1 member. The median household size across all customers is 6 for BELECOM and 5 for BBOXX. There was no evidence to suggest that household size was linked to SHS size and households with few members were as likely to acquire a larger SHS as a household with a large number of members.

6.4.3 Employment Status

Suppliers were asked to record the employment status of the customer purchasing a SHS from a list of pre-determined options. There were several limitations with this data (see section 5.4) which meant some data needed to be grouped. The data for BELECOM (Table 7) and BBOXX (Table 8) demonstrates that unemployment levels are high for both male and female respondents across all camps. In all cases, except for BELECOM customers in Nyabiheke camp, women are also more likely to be recorded as unemployed than males. However, it is important to note that analysis of the supplier sales reports and customer monitoring datasets indicates that approximately 30% of women are keeping house and/or looking after children. In Gihembe and Nyabiheke less than 10% of respondents are recorded as being an employee or receive a wage of some description. However, for males in Kigeme camp, this is significantly higher at 51.5%. A small percentage (<3%) reported that they had a different occupation such as community mobiliser or volunteer. The data also indicates that BBOXX customers are more likely to be a business owner or self-employed than BELECOM customers and that there are significantly more business owners in Nyabiheke camp than Kigeme and Gihembe.

	Gihembe		Kigeme		Nyabiheke	
	Male	Female	Male	Female	Male	Female
Business owner/ manager/ self-employed	3.3%	2.1%	15.2%	11.9%	12.6%	14.2%
Employee receiving wage/ incentive worker	8.3%	0.9%	51.5%	10.6%	4.2%	6.5%

Other (incl. community mobiliser and volunteer)	0.6%	0%	0%	0.2%	2.8%	0%
Unemployed/ laid-off/ looking for work[4]	87.8%	97%	33.3%	77.2%	80.4%	79.3%

Table 7 - BELECOM customer employment status based on supplier monitoring forms

	Gihembe		Kigeme		Nyabiheke	
	Male	Female	Male	Female	Male	Female
Business owner/ manager/ self-employed	6.5%	8.1%	29.3%	26.2%	42.3%	37.9%
Employee receiving wage/ incentive worker	12.3%	9.1%	9.5%	11.1%	6%	5.6%
Other (incl. community mobiliser and volunteer)	1.2%	2.5%	0.8%	0.7%	0%	0%
Unemployed/ laid-off/ looking for work	80%	80.2%	60.5%	62%	51.6%	65.5%

Table 8 - BBOXX customer employment status based on supplier monitoring forms

Table 9 shows a comparison made between the data collected as part of the RE4R assessment phase and the suppliers' data to establish whether SHS customers were similar to the camp population generally. It demonstrates that SHS customers in Gihembe and Nyabiheke have a similar employment status to the camp-wide population. However, in Kigeme, SHS customers were more likely to be receiving a wage than the camp-wide average. It is not clear from the data why this is the case, however, it could be linked with inconsistencies in the way data was collected by suppliers (section 5.4).

	Gihembe		Kigeme		Nyabiheke	
	Wage	Non-wage	Wage	Non-wage	Wage	Non-wage
RE4R Assessment Phase	21%	79%	17%	83%	44%	56%
SHS Customers	12%	88%	33%	67%	33%	67%

Table 9 - A comparison of the employment status of BELECOM and BBOXX customers and camp-wide data collected as part of the RE4R assessment phase

6.5 Default Rate

In this analysis, a defaulting customer has been unable to make a payment for their system within 30 days of the due date or who has had the system repossessed by the SHS supplier due to continued non-payment. Only a small number of customers were in default at the point when the data was analysed (Figure 9). For BELECOM, the default rate across all systems and camps was 18% and the repossession rate was 3%. For BBOXX customers, the default rate was 2.6% and the repossession rate was 0.7%. There was a negligible difference between male and female customers in terms of their likelihood to default. For example, among BELECOM customers the average default rate was 18% for men and 18.2% for women and among BBOXX customers the default rate was 1.25% for men and 1.39% for women. Similarly, the gender of the customer had little impact on the likelihood of a system being repossessed.

[4] This includes those recorded as keeping house or raising children full time.

For BELECOM the repossession rate was 3.1% for men and 2.6% for women and for BBOXX it was 0.46% for men and 0.2% for women. The data suggests that approximately 12% of BELECOM customers with the 20W or 22W system defaulted compared to just under 34% for those who had the 12W system. In comparison, the default rate for BBOXX customer was less than 3%. However, it is worth noting that default levels are higher among customers who had the 12W BELECOM system because there was widespread dissatisfaction among customers about the system's performance.

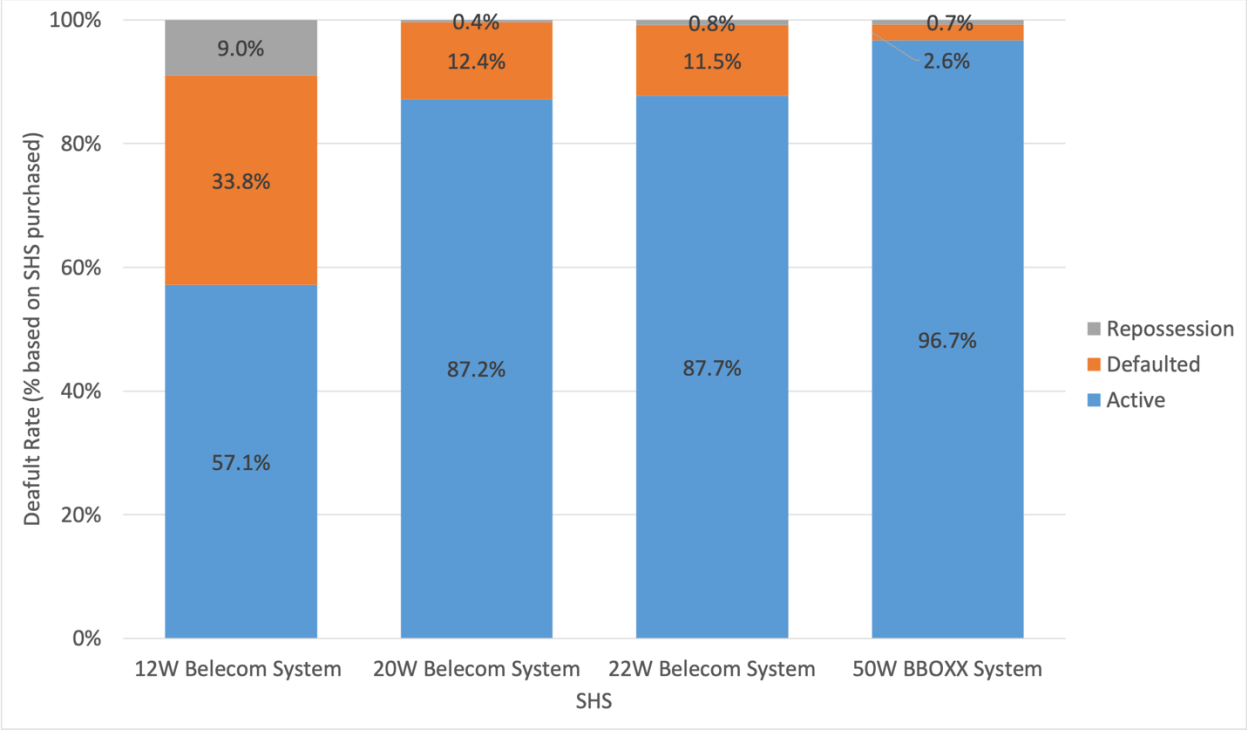

Figure 9 - BELECOM and BBOXX default rates by SHS

6.6 Social Factors

The customer monitoring survey included several questions that aimed to evaluate the impact the SHS was having on the customers quality of life, for example, education and safety. Most impact is associated with the improved quality and duration of lighting provided by the SHS which is also well reported in the literature (Azimoh et al., 2015; Diallo & Moussa, 2020; Jeuland et al., 2021). For example, 98% of households stated that the SHS was their primary lighting source and 94% stated that their SHS met their basic lighting needs. Figure 10 provides an overview of these findings and demonstrates that in most cases the SHS installed has improved people's perception of safety, improved children's[5] ability to study and enabled people to carry out household chores or recreational activities after dark. However, evidence on whether the SHS improved people's ability to work do productive activities such as do business after dark is less clear. These results are possibly skewed by several factors including respondents who replied "no" because they did not own or operate a business. It is also worth noting that although respondents indicated that the SHS had allowed study after dark it is not clear

[5] Figures regarding whether a SHS has enabled study exclude households where there isn't at least one member under the age of 18

whether this is a perceived or actual increase or whether it resulted in any improvements in educational attainment.

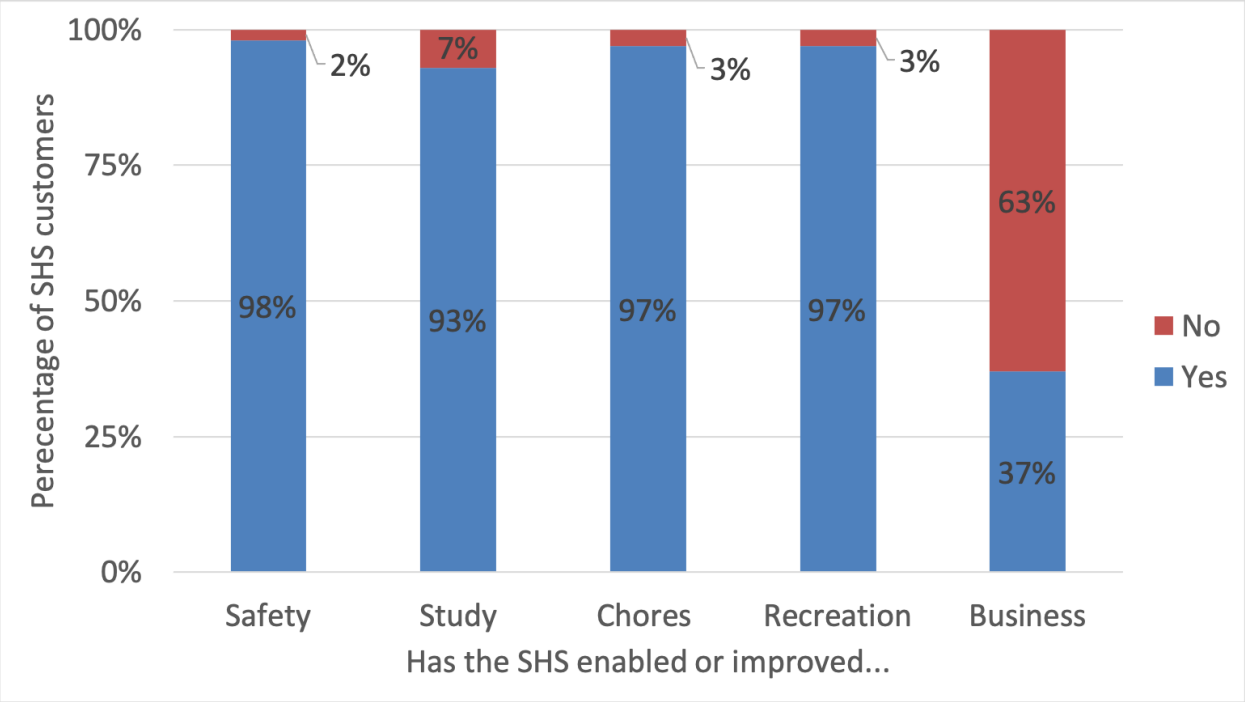

Figure 10 - Social impact of SHS across all systems and camps

6.7 Technical Factors

A proportion of customers reported that they experienced a technical issue with their SHS at some point after installation (Figure 11). Issues were more common for BELECOM customer (57% for the 20W SHS and 60% for the 12W SHS) than for BBOXX customers (28%). Although the specific technical issue was not recorded as part of the survey, anecdotal evidence suggests that issues were primarily related to the battery, cables or switches. These issues are discussed further in section 7.3.

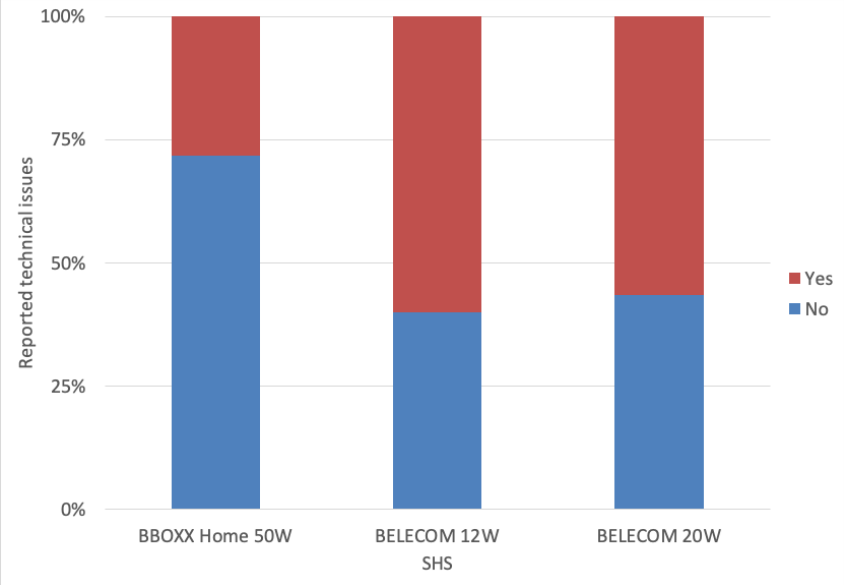

Figure 11 - Percentage of SHS customers that reported a technical issue

7.0 Discussion

This section reviews the findings against the diffusion on innovations framework (Table 3) to evaluate the challenges facing the adoption of systems and to identify opportunities to increase sales in the camps.

7.1 Relative Advantage

According to Rogers (2003) for an innovation to be successful, it needs to be more advantageous than the solution it replaces. Of most importance is the perceived relative advantage a technology has (Rogers, 2003).

Overall, the volume of BELECOM and BBOXX SHS sales in the camps (Figure 4 - Monthly and Cumulative sales of BELECOM SHS in Gihembe, Nyabiheke and Kigeme campsFigure 5 - Monthly and Cumulative sales of BBOXX SHS in Gihembe, Nyabiheke and Kigeme camps in addition to the positive impacts reported (Figure 10) indicates that the SHS offered provide an advantage compared to the energy solutions they replace. This is supported by the evidence demonstrating that households are willing to redirect an already constrained household income towards the costs of a SHS (section 6.2) and that the second most popular reason for purchasing a SHS is that households “just wanted it”. Feedback provided to the field coordinators following the first sales also consisted of positive accounts from customers and there was anecdotal evidence of newly established businesses, children being able to study at night and families enjoying the entertainment technologies that were now available. This is because, before the introduction of SHS to the camps, households and small enterprises typically relied on low-tier lighting technologies – such as candles, lights on mobile phones and improvised battery torches – to meet their lighting needs and had little or no access to electricity (Sandwell et al., 2020).

The main advantage provided is associated with improved lighting which is supported by previous research that has established that SHS have higher-quality lighting and can enhance the evening lives of

households (Ebers Broughel, 2019; Holtorf et al., 2015a). The findings of this study suggest households use their SHS for lighting and 94% reported that it met their basic needs (section 6.6). Furthermore, 98% of households used their SHS as their primary source of light which is important because previous analysis by Ebers Broughel (2019) found that households with access to a SHS were still utilising secondary lighting sources, potentially negating some of the benefits.

The impact of reduced expenditure and time savings associated with a reduction in candle use and the ability to charge mobile phones in the home is also supported by statements made by customers. For example, one customer said, “we wanted to end the era of darkness and reduce the amount we […] spend on candles and phone charging”. However, not all the SHS provided an acceptable advantage and there was widespread dissatisfaction with the 12W SHS that was initially offered by BELECOM (discussed further in section 7.2).

Access to a SHS improved 98% of households' perception of safety in the camps, which contradicts other studies' findings (i.e. Dynes *et al.*, 2014; Gunning, 2014). The data also suggest that access to a SHS enabled children to study in 93% of households and enabled 97% of households to do chores or engage in recreational activities. However, caution needs to be applied to these findings because there are examples in the literature demonstrating that people sometimes tell data collectors what they want to hear (Sovacool et al., 2011). Attempts to address this in this study have been made by triangulating the findings with the field coordinators' observations and by regular consultation with experts in the field and project partners. Anecdotally, having access to a SHS was particularly valuable during the Covid-19 lockdown because, households with a SHS powered radio were able to access public health information that was being transmitted and children could listen to educational programmes while schools were closed (Grafham et al., 2021).

There are also opportunities to increase the relative advantage provided, for example, some customers reported that they would like additional appliances such as a radio, television or additional lights with their SHS. Furthermore, the introduction of SHS to the camps didn’t automatically lead to business opportunities or income generation opportunities for households that acquired one, indicating that additional mechanisms are needed to support this transition. For example, only 37% of respondents stated that a SHS helped businesses in the camps, primarily through being able to extend opening hours into the evening. It has not been possible to determine from the data what impact this has on the business's income.

7.2 Compatibility

According to Rogers (2003) for an innovation to be perceived as compatible it needs to support traditional values, match previous experiences and meet end-user needs. Widespread diffusion can be limited if these factors are not supported and innovations often fail because they are only marginally different to existing practices (Rogers, 2003).

The volume of SHS sales (Figure 4 and Figure 5) and the low default rate is an indication that the SHS offered and the delivery mode are compatible with customer needs. However, customers reported problems that demonstrated the SHS were sometimes not compatible with their needs or did not meet their expectations. For example, the 12W BELECOM system was criticised by customers as not being powerful enough and led to BELECOM removing it for sale. However, users of the more powerful

BELECOM and also the BBOXX system also reported similar concerns. For example, one customer stated that the SHS was good but the capacity needed to be increased because it didn't last when all their appliances were connected. This is in line with similar findings in Sri Lanka, where the problem many households had with their SHS was that it could not power many of the devices they wanted to use (Turner, 2019). Customers regularly stated that they wanted to connect additional appliances including lights which reflect findings made by Collings and Munyehirwe (2016) that suggested households in Rwanda wanted a larger SHS with more lighting capacity. The limited capacity of SHS is also one of the reasons why households often express a preference for a grid connection (Boamah & Rothfuß, 2020; Conway et al., 2019; Derks & Romijn, 2019). However, in the case of Rwanda, although the government classifies the camps as on-grid locations, there is no intention of connecting households to the grid network.

In line with findings made by Bisaga (2018), one of the main reasons SHS failed to meet the needs of some households in the camps appears to be linked to the Rwandan climate which often has a high percentage of cloud cover, particularly during the rainy season and in mountainous areas. Multiple households reported that problems were worse during the rainy season or when the weather was bad. However, this could also be caused by end-users having misconceptions about the SHS capabilities which can potentially be mitigated by education programmes and a long learning period to help users optimise the use of their systems (Ebers Broughel, 2019; Holtorf et al., 2015b).

Another common concern that was reported anecdotally among customers was related to resettlement. Refugees wanted to understand what will happen to their payments if they were successful through the resettlement scheme. This is similar to issues identified by Barrie and Cruickshank (2017) who found that the lack of portability and inability to transport a SHS easily was a major limitation for some customers.

Insufficient and unpredictable incomes are also often cited as a reason why SHS are not easily diffused in refugee camps (Ebers Broughel, 2019; Whitehouse, 2019). However, this research found that households in the camps are willing and able to pay for SHS. Furthermore, the default and repossession rates for BBOXX (~4%) and BELECOM (~13%) are both low once the defaults related to the 12W BELECOM SHS are excluded from the analysis. This finding indicates that the PAYG delivery model and the monthly payment amount is compatible with approximately 32% of households in the camps.

Existing research suggests that the monthly payments for a SHS can be partially offset with savings households make by not purchasing alternative fuels such as candles and batteries (Ebers Broughel, 2019). While this study supports this finding, it also demonstrates that households redirect income from other areas such as food (Figure 7**Error! Reference source not found.**). While this issue is not well reported in the literature related to electricity access it is regularly discussed in the literature related to cooking energy access. Further analysis is important because evidence suggests that diverting income away from food can lead to malnutrition, weak health, and enhances causes of mortality (Barbieri et al., 2017). However, this issue was monitored carefully by the RE4R project partners, particularly UNHCR and the Rwandan Ministry of Emergency Management to ensure any adverse outcomes were minimised and that it did not impact the ability of UNHCR to meet its core protection remit.

Overall, the analysis suggests SHS remain too expensive for ~70% of households. This is partly demonstrated by the dramatic fall in SHS sales that occurred when BBOXX met its sales quota and their systems were no longer subsidised. This is also broadly in line with Chadwick (2019) who estimated -

based on the RE4R assessment phase data collected in 2018 - that 25% of refugees in the camps are willing to pay 2,700 RWF (US$2.70) per month for a SHS, 50% were willing to pay 1,500 RWF (US$1.50) per month and 75% were willing to pay 300 RWF (US$0.30) per month. Based on this data less than 25% of households would adopt at a close to market rate.

There are also other issues with the compatibility of the payment system identified in the data. For example, a disadvantage of a PAYG SHS compared to traditional fuel sources is that regular payments are needed which can present challenges for those receiving irregular incomes (Barrie & Cruickshank, 2017). As a result, SHS needs to mirror existing energy financing mechanisms such as small regular payments rather than large upfront payments (Bisaga & Parikh, 2018; Holtorf et al., 2015b; Muchunku et al., 2018; Yadav et al., 2019). SHS customers also identify this issue in the camps who wanted the flexibility to move their SHS payment date to line up with the cash transfer they receive from the World Food Programme.

7.3 Complexity

According to Rogers (2003), an innovation needs to be easily understood and operated by end-users if widespread diffusion is to be achieved. Previous research has also already identified that SHS are more complicated than other energy technologies such as solar lanterns and there can be a misunderstanding about how the SHS works (Barrie & Cruickshank, 2017).

The data in this study indicate that most SHS were installed correctly by the suppliers and that customers understood the PAYG payment system. For example, only one customer out of 185 surveyed said the payment was an upfront payment rather than a payment plan, however, there was more confusion among customers about the contract duration and the RE4R field coordinators received a lot of questions about payments from refugees. For example, 54% on BBOXX customer and 58% of BELECOM customers correctly identified that the payment term was 36 months (see Table 4). This issue was also identified by Barrie and Cruickshank (2017), who found that SHS customers paying via PAYG delivery models believed they owned the system even if they hadn't made all the payments required. Customers also expressed some confusion with other parts of the payment system. For example, some didn't know what would happen if they couldn't make the payment when it was due, didn't know how to pay or weren't sure what happened at the end of the contract period. These issues suggest that the SHS delivery model is either too complex for users, that suppliers are not effective at conveying the information clearly or that refugee's ability to source accurate information is constrained.

There is also a link between payment and maintenance complexity. For example, there was evidence that customers didn't know what to do about a technical issue or could not get the help they needed. In some cases, they withheld payment for their system as a result which then caused further problems and dissatisfaction. This problem has been well established in the literature, for example, Ebers Broughel (2019) has established that households are sometimes unaware of how to deal with maintenance issues. Turner (2019) also found that the decision to stop repayments is not always because of a lack of funds but because systems are not working correctly.

There are several cases where customers reported that they had a technical issue with the system when it was the capacity of the system that was the problem. This challenge was exacerbated for BBOXX customers who experienced significant challenges accessing after-sales services because BBOXX did not

maintain a permanent presence in the camps, preferring to use a customer service hotline and because the BBOXX sales agents were paid on a commission-only basis and were not trained or paid to deal with technical issues. For example, one customer reported that they spent 4,000 RWF (US$4.00) to travel to the BBOXX shop in the nearest town to get their SHS fixed and other customers reported that they were unable to call the BBOXX call centre because they didn't have airtime on their mobile phones. This highlights the importance of expectation management and the need to explain the SHS capabilities to customers clearly.

There was evidence that independent technicians in the camps could repair simple technical issues such as broken switches and cables but because these repairs were not carried out by the suppliers the cost needed to be paid for by the customer and such a repair also invalidates the warranty. As a result, SHS customers rarely used this service. However, future projects could seek to utilise this local expertise, for example, suppliers could provide training to local technicians and certify them to carry out 'simple' repairs. This could improve customer satisfaction as repairs could be carried out faster and reduce service and maintenance costs for suppliers, especially if they are unable to maintain a permanent presence in the location. Furthermore, this would provide access to income-generating opportunities for the technicians in the camps.

7.4 Communication

This section discusses the impact that different communication methods had on the diffusion of SHS in the camps. According to (Rogers, 2003) the two main communication channels through which information can be disseminated are: (1) direct group promotion such as sales events and radio advertisements; and (2) interpersonal methods such as conversations customers have with the sales agents or neighbours.

Both the SHS suppliers and the RE4R project used a range of communication methods to raise awareness of the SHS being provided. For example, BBOXX conducted awareness-raising activities such as 'market storming activities', distributing leaflets to households and carried out product demonstrations. However, it is important to note that 16% of the households surveyed in the assessment phase of the RE4R project already had access to SHS and there was some awareness of the technology and its benefits, although possibly also misconceptions before the suppliers entered the camps.

Brand awareness is also an important issue (Corbyn & Vianello, 2018) and there was evidence that BBOXX benefited from being well-known in Rwanda and that BELECOM, as a relatively new entrant into the SHS market, had to compete against them for recognition. However, the field coordinators' observations suggest that customers wanted to change from BBOXX to BELECOM due to the comparative cost of the system demonstrating a degree of supplier competition and product choice once customers were familiar with the options available to them. This demonstrates that as customers start to engage in the SHS market they become more aware of the relative advantages and disadvantages of the technologies available to them.

BELECOM also carried out mass meetings, product demos and focus groups to promote their SHS in the camps. Both suppliers recruited and trained sales agents from the camp population to sell SHS. This is

because previous research has established that the use of sales agents has led to SHS dissemination in other markets (Holtorf et al., 2015a).

The data from this study suggests that sales agents were the most influential factor in the customer decision-making process (Figure 8) which conflicts with the findings of authors such as Barrie and Cruickshank (2017) who found that sales agents only "moderately improve sales". There are several reasons why this could be the case including that the sales agents in the Barrie and Cruickshank (2017) study were mainly local shop owners rather than agents specifically employed to sell SHS. The level of training received by sales agents was also likely to be more comprehensive which meant sales agents could articulate the benefits of purchasing a SHS to customers more clearly. Furthermore, it is possible that respondents reported that sales agents were most influential because this is who they bought the system from. This does not necessarily reflect that customers may have benefited from the broader engagement activities that informed them of the SHS benefits before the systems were available. The use of sales agents also needs to be monitored carefully, particularly when they are paid via commission. For example, there were some reports of BBOXX sales agents telling potential customers that the BELECOM system was weak, leading to confusion among end-users.

The findings of this study also contradict research by McEachern and Hanson (2008) that suggests SHS suppliers target religious leaders and religious centres to increase adoption levels because in this study opinion leaders played a minor role in influencing customers to acquire a system. However, because religious leaders were not directly involved in the RE4R project it is not possible to confirm whether their involvement would have led to further adoption.

8.0 Limitations

Although the validity of using diffusion of innovations theory as a framework for investigating the adoption of SHS has been confirmed, there are some limitations associated with this study.

This paper only assesses the diffusion of the SHS provided by BBOXX and BELECOM through the RE4R project in the camps and does not consider what impact the availability of alternative technologies such as solar lanterns, mini-grids or grid extension would have on rates of diffusion. Furthermore, it has not been possible to consider the role access to existing SHS technologies had on the diffusion of the SHS provided by the RE4R project. While this demonstrates demand for SHS where there is limited availability of other energy options, it doesn't reflect what diffusion might look like if a vibrant energy market were created in the camps. The SHS suppliers were also supported financially and logistically by the RE4R project and did not start operating in the camps of their own accord.

The research only evaluates diffusion levels in three protracted refugee camps in Rwanda, which has progressive policies supporting refugees' integration. While caution needs to be taken before inferring that similar diffusion patterns would be seen in other refugee contexts, the authors consider the camps to be similar to refugee camps in neighbouring countries such as Tanzania, Burundi, Uganda, Ethiopia, Sudan and Kenya.

There were also logistical and ethical challenges associated with collecting the data presented in this paper (discussed further in section 5.0). Assumptions were made to clean the data and although efforts were made to ensure these changes accurately reflect the situation it possible that they impact the

findings presented. The data was also collected primarily for project activities (discussed in section 5.0) rather than specifically for this analysis.

The data also only covers 12 months which is a third of the contract period for the SHS offered. As a result, the research can only cover a limited period of the customer journey and only systems acquired in the initial phases of the project were owned for a full calendar year. Furthermore, BBOXX only sold SHS in the camps for a short period and was not active in the camps once it had researched its sales quota (discussed further in section 6.1 and 7.2). As a result, it is difficult for the research to identify challenges that may occur at different times of the year. This is particularly relevant for customers whose income fluctuates through the year which may impact their ability to make payments for their SHS. Issues associated with the duration of the contract may also only become apparent over a longer-term.

During the 12 months being assessed, sales and after-sales support were impacted by lockdown restrictions associated with COVID-19 as discussed in section 5.6. It is worth noting that the impact of COVID-19 on people's lives in the camps is likely to be extensive. However, the lockdowns in Rwanda and the United Kingdom have made it difficult to assess these issues in detail as part of this study.

9.0 Conclusion and Further Work

This paper applies diffusion of innovation theory to evaluate SHS delivery in three refugee camps in Rwanda. The aim was to understand the relationship between the technology and community in terms of relative advantage offered, socio-cultural compatibility, system complexity and communication channels. Overall, there were many similarities between BBOXX and BELECOM and despite taking different approaches to sell their SHS in the camps, both have sold a significant number of SHS in the camps. In total, the suppliers sold 3,103 SHS which represents approximately 32% of households. This is also despite facing significant challenges associated with COVID-19.

The SHS adoption levels and the positive feedback from customers indicate that the SHS acquired by customers provide an advantage for households compared to existing energy options and are compatible with the end-users needs. The evidence suggests that SHS can meet basic household lighting and mobile phone charging requirements and that SHS helped children and adults study or work after dark, enabled recreation activities and improved people’s perception of safety in the camps. However, this data has been repurposed and further insight is needed to evaluate these findings fully. For example, the number of additional hours children can study and its impact on their educational attainment is not clear. There are also gender issues that warrant further investigation, for example, how are impacts split between male and female household members. These findings would help inform future projects and strategies to ensure the best technologies are provided.

The research also identified issues with after-sales service and the maintenance of systems that need to be addressed by future projects. One solution is for the SHS supplier to set up a permanent presence in the camp or nearby in the host community. However, this is potentially impractical in areas where there are low diffusion levels and the cost of maintaining a store permanently is too high. Future research could investigate how SHS suppliers can be supported to provide more effective long-term support to customers, for example, by evaluating the viability of mobile maintenance and customer service clinics

or through better training and long-term employment of technicians and sales agents. In particular, evaluating how existing expertise in the camps can be used to address minor technical issues. Implementing an affordable or free method for customers to contact the SHS suppliers should also be an essential consideration for future projects.

Refugees also consistently requested more powerful SHS partly because the Rwandan climate impacted the performance of systems but also because they wanted additional appliances and lights. However, affordability and payment flexibility remain present and even the cheapest SHS provided by the project remained out of reach of the poorest households. Furthermore, the data suggest that refugee households have a high level of agency in their financial decisions and can set household priorities accordingly. However, their constrained incomes mean they are possibly redirecting or diverting income from important areas such as food and other essential items which could have potential implications for their health, wellbeing and safety that warrant further analysis to mitigate negative side effects. It was not possible to determine whether a SHS customer was more or less likely to default after a certain period of time. Further work exploring why customers default including common default triggers and ways these could be mitigated would be beneficial.

There are policy changes that can be implemented to address issues identified including aligning SHS payment dates with the cash transfers refugees receive from WFP and allowing customers to pay more towards their SHS when they have funds available. Future projects should also look at options to provide funding as a 'safety net' for customers who cannot pay for their SHS because of a temporary cash-flow issue. Despite these recommendations, how to increase the affordability of SHS among low-income households remains a significant challenge that needs to be addressed if the policy objectives set out in SDG7 and the UNHCR clean energy challenge are to be achieved.

Acknowledgements

The authors would like to acknowledge the Practical Action, UNHCR and the IKEA Foundation for collaborating on this project Specific thanks to Sarah Begg, Tracy Tunge, Denyse Umubyeyi and Laura Clarke for collaborating on the design and implementation of the data collection strategy and for reviewing the draft version of this paper. A special thanks also to the field coordinators Berthille Kampire, Patrice Izerimana and Theogene Ndatimana whose work in the camps and insight has been invaluable. Peter Thomas would also like to thank Dr Karen Bell for her support.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The EPSRC funded the corresponding authors PhD research and the IKEA Foundation funds the RE4R project. The funders had no role in the design, implementation or analysis presented in this paper.

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