SUSTAINABLE SOLAR E-WASTE AND BATTERY TECHNOLOGY MANAGEMENT:

A QUALITATIVE STUDY OF OFF-GRID SOLAR MARKETS ACROSS UGANDA AND SENEGAL

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This report assesses the market opportunities and challenges related to end-of-life management of solar home systems (SHS) and battery technologies in Uganda and Senegal, with the goal of informing investments in SHS end-of-life management across sub-Saharan Africa. The study included many stakeholders along the SHS value chain, including SHS distributors, e-waste recycling companies, and battery technology distributors. The USAID/SOGE team provided financial support and invaluable technical insights that shaped the scope of this study. We thank the SHS distributors, e-waste recycling companies, and battery technology distributors interviewed in this study for their valuable perspective. We thank the CLASP team and Jit Bhattacharya for their technical insight and data contributions, supplementing the overall market analysis. We would also like to acknowledge the Uganda and Senegal-based research assistants who collected data and supported the analysis. Special thanks go to Molly Dean, Senior Advisor, Scaling Off-Grid Energy, USAID, Taha Gaya, Analyst, Scaling Off-Grid Energy, USAID, and Dr. Catherine Wolfram and her team at the University of California, Berkeley, for their technical insights. Dr. Maggie Linak, USAID, coordinated the research agreement.

RESEARCH CONTEXT

Sub-Saharan Africa (SSA) has an abundance of untapped renewable energy resources that could address both the limited supply of modern, safe, and affordable energy sources available to rural communities in the region. Some researchers estimate that alternative, technologically feasible sources of renewable energy could exceed current consumption levels in SSA by 10- to 12-fold (Deichman et al, 2011). There has been a rapid and significant increase in the sale of household solar systems (SHS) throughout SSA over the past decade, driven by an increasing number of private companies serving households and businesses (Nygaard et al, 2016). However, these sales can hardly keep up with population growth and demand continues to outweigh supply. In response, the off-grid solar sector continues to expand operations across SSA, with support from international donors and development financial institutions. As the sector matures, it is also working to ensure that its sales channels for SHS distribution across East and West Africa are sustainable, leaving behind a positive legacy for its rural customers.

Efficient management of solar electronic waste (e-waste) at the end-of-life is an essential aspect of ensuring this legacy. Given the remote and hard-to-reach customer base that SHS distribution companies typically serve in the region, the collection, repair, and recycling of products presents a significant logistical challenge.

This report presents the results of a qualitative research study exploring the operational and logistical challenges that SHS distribution companies face in efficient solar e-waste management. This study presents key insights from local solar companies with operations across Uganda and Senegal, as well as a household survey exploring consumer behavior around solar e-waste collection, recycling, and repair. These findings seek to inform companies, donors, investors and governments alike in developing efficient, effective corporate policies for sustainable solar e-waste and battery collection, recycling, and repair. Given SSA's growing demand for affordable, modern solar household systems, the time to ensure a positive industry legacy is now.

SECTION 1: BACKGROUND

The United States Agency for International Development (USAID), in partnership with other donors under the Scaling Off-Grid Energy (SOGE) Grand Challenge for Development, assists companies to deliver clean, affordable, and reliable energy services to millions of households across sub-Saharan Africa (SSA). Given the ambitious market growth this requires, USAID and its partners have a vested interest in the social and environmental impact of the product design, manufacturing, use, and end-of-life processing of solar home systems (SHSs).

Recent advancements in pay-as-you-go (PAYGO) technology have enabled SHS companies to increase access to energy in unelectrified communities at an unprecedented rate. However, despite the significant positive environmental and health benefits of displacing kerosene and wood-burning fuel at the household level, SHSs often contain toxic heavy metals and hazardous chemicals, creating e-waste disposal challenges and unintended negative environmental impacts at both the manufacturing and end-of-product-life stages. Since the technology is new, most of the products sold thus far are still in use; however, a large volume of product will be approaching end-of-life in the next decade. Currently, there are few stringent waste management policies at the company, municipal, or national levels.

This report seeks to inform companies, donors, investors and governments alike in developing efficient, effective corporate policies for sustainable solar e-waste and battery collection, recycling, and repair. With the anticipated growth in SHS distribution, there is also a need to understand the availability and viability of low-cost, low-toxicity, high performance battery solutions for home use. This research also explores novel battery technology trends to help inform companies as they seek to improve solar product offerings.

Using this research as an initial discussion point, USAID has enlisted the ResilienceAfrica Network (RAN) based at Makerere University, the University of California Berkeley (UCB), and the University of Dakar to explore best practices around solar e-waste and battery technology end-of-life management. As the industry matures and more stringent e-waste regulations are established by governments, companies will be equipped to continue to offer increasingly sustainable, durable, and high quality energy products and after-sales services. This research partnership will be a base from which the industry can learn, test, and innovate new models of e-waste management to ensure a positive environmental legacy.

SECTION 2: RESEARCH OBJECTIVES AND METHODOLOGY

2.1 RESEARCH STUDY OBJECTIVES

The primary objective of this study was to assess the market potential, best practices, and challenges related to end-of-life management of SHS and battery technologies across SSA. The research included explorations of:

- The local market structure and broader ecosystem for SHS and battery end-of-life management in Uganda and Senegal, two sample economies representative of the markets in East and West Africa
- An exploration of the market opportunities and challenges related to SHS end-of-life management
- An exploration of consumer behaviors around SHS and battery end-of-life management

2.2 RESEARCH STUDY DESIGN

This was a cross-sectional study employing qualitative methods of data collection. It included a market analysis of the off-grid SHS and battery markets across Uganda and Senegal, followed by key interviews exploring current operational practices around solar product take-back and warranty programs, after-sales servicing for product repairs or upgrades, and waste management of solar and battery technologies at the end of products' lifespans. This research also included a randomized sampling of households surveyed across rural Uganda to better understand consumer behavior around these company policies.

2.3 RESEARCH SAMPLE POPULATIONS

The research team implemented the study in Uganda and Senegal with stakeholders across the SHS value chain, including SHS distributors, battery manufacturers, and e-waste recycling companies. These stakeholders represented companies within the SHS ecosystem operating in Uganda, Senegal, and on a multi-country or global scale. The global stakeholders were targeted to give a holistic perspective on SHS distribution, e-waste management, and emerging battery technologies for SHS application.

The sample size for this assessment was not intended to achieve statistical generalizability, but to represent local market saturation in Uganda and Senegal, thus the research covered several categories of stakeholders representing 19 companies operating in Uganda, 26 in Senegal, and 20 companies with an international reach, as well as 320 households in Uganda. Appendix A provides the full list of stakeholders included in the assessment.

2.4 DATA COLLECTION PROCEDURES

An initial desk review focused on the current ecosystem for e-waste management for off-grid SHS, the opportunities and challenges associated with e-waste management, the local market structure, and the potential availability of new and emerging battery technologies appropriate for off-grid SHS. The review included policies, strategies, reports, protocols, regulations, studies, and other related documents. The research team collected qualitative data from selected industry stakeholders via email, telephone, and in-person communication. Interviews included representatives from technology and innovation, marketing and finance, sales, community outreach, and quality control departments within local and international SHS distributors, battery technology companies, and e-waste recycling companies. The key informants provided information related to the status of the SHS waste management ecosystem and market opportunities and challenges for both SHS and emerging battery storage technologies. The research team piloted the survey with three SHS stakeholders not included in the study sample to ensure quality and relevance of the tools.

2.5 KEY VARIABLES FOR DATA COLLECTION

The study considered several variables affecting overall market dynamics within three categories:

- Variables influencing SHS distributors' best practices for solar e-waste management, which included:
  - Company take-back programs (both in and out of warranty);
  - Product collection location, logistics (customer-driven, informal market, or company-driven), and associated costs;
  - After-sales servicing for product repair (both in and out of warranty);
  - Recyclability of SHS and batteries currently on the market;
  - Salvage and second-use value of SHS components and batteries currently on the market;
  - Markets for second-use applications of SHS components and batteries;
  - Third-party service providers for collection, sorting, and aggregation of solar e-waste and battery products, and associated costs;
  - Consumer behavior around solar e-waste management (perceptions of disposability, product maintenance, and repair, both in and out of warranty; incentives to participate in company take-back programs; and general e-waste handling/disposal practices).
- Variables influencing the economic viability of solar e-waste management service providers, which included:
  - Existence of supply chain partnerships to achieve a critical mass of material volume for processing;
  - Efficiency of logistics for sourcing, collection, sorting, and processing of e-waste materials;
  - Production facility capacity to manage high volumes of diverse e-waste materials;
  - Critical supply volume of materials with recyclability and/or salvage value;
  - Existence of collection points with company, local government, and/or community buy-in;
  - Identified monetization opportunities for repurposed materials in secondary markets; and
  - Regulatory environment influence on ease of material sourcing, processing, and hazardous waste management.
- Variables influencing the market potential of emerging battery technologies with off-grid SHS applications, which included:
  - Durability, longevity, performance, affordability, and reliability;
  - Toxicity and recyclability of products, without the need for hazardous materials handling considerations; and
  - SHS distributor capacity to integrate new product testing

SECTION 3: KEY INSIGHTS ON SOLAR E-WASTE MANAGEMENT IN UGANDA AND SENEGAL

This section summarizes the key market opportunities and challenges for SHS end-of-life management in Uganda and Senegal.

TABLE 1. SOLAR DISTRIBUTOR INTERVIEW RESULTS

VARIABLE	% ANSWERING YES
Has an existing e-waste management plan	53%
Has a plan for a future e-waste disposal program	50%
Currently recycling old SHS components (including batteries)	29%
Perceives value in e-waste (now or in the future)	76%

TABLE 2. E-WASTE RECYCLING COMPANY INTERVIEW RESULTS

VARIABLE	% ANSWERING YES
Collects SHS batteries only	29%
Collects e-waste and batteries	57%
Collects only scrap metal and plastics	14%

3.1 SHS CUSTOMER BASE AND GEOGRAPHIC COVERAGE

Most SHS distributors interviewed operate in several African countries, including significant market coverage in Uganda and/or Senegal. While most SHS consumers were individual households, companies also reported sales to local businesses, government ministries, and NGOs. NGOs represented a larger customer base than businesses in Senegal, since donors and NGOs oversee most of the country's rural electrification efforts, though the availability of private sector off-grid energy services is growing rapidly. Most of the SHS distributors and e-waste recycling companies interviewed for this study were located in urban and peri-urban centers, with customer bases sprawled across rural regions.

3.2 SHS PRODUCT COMPOSITION AND PRICING

SHSs included in this study typically consisted of a solar panel, a battery, a regulator, and an inverter. Most companies surveyed manufacture or distribute glass-plated solar panels with laminated back sheets and aluminum frames.

Most companies supply both polycrystalline and mono crystalline solar panels, protected with a sealant made of polyester terephthalate (PET) or Ethylene Tetrafluoroethylene (ETFE), with a back sheet composed of aluminum or other flame-retardant material. The PV panels vary in power output but are composed of generally similar materials and primarily provided lighting. SHSs often included other appliances, the most popular of which were radios, televisions, phone chargers, lighting, and fans.

The most commonly reported type of battery in use was lead-acid, due to its durability, low cost, and reliable performance. Popular lead-acid battery brands in Uganda are Uganda Batteries Limited and Chloride Exide Batteries. The most commonly used brands in Senegal were Victron and Sukam. Lithium-ion batteries were also common, especially in larger systems, but they are more expensive and more difficult to recycle or dispose. Respondents also reported several alternative technologies, including Absorbed Glass Mat (AGM) batteries, across various product lines.

TABLE 3. COUNTRY OF ORIGIN OF DISTRIBUTED SHS PRODUCTS

PRODUCT	COUNTRY OF ORIGIN			
	FRANCE	GERMANY	CHINA	OTHER
Batteries	4.5%	12.5%	66%	17%
Solar panels	8%	13%	72%	7%
Regulators	11%	7%	69%	13%
Solar Lighting	21%	13%	33%	23%

The price of SHSs varies between companies, with batteries being the main driver. Import taxes also play a large role in the end users' cost. Most SHS components are tax exempt, but batteries are often charged a 25 percent duty unless a company can prove the batteries are to be used for an SHS by shipping them in the same container. Components are often sourced from multiple suppliers, thus companies are often unable to meet this requirement.

3.3 SHS DISTRIBUTION MODELS AS THE BACKBONE OF AFTER-SALES SERVICES

Companies' distribution models are often the backbone of their after-sales and collection services. SHS distribution agents serving last mile customers are also often the point person for warranty servicing and end-of-life product collection and disposal. Branded branches and retail shops also operate as collection points and/or warranty servicing locations, though the viability of this model is largely dependent on technician availability in rural sales regions. SHS companies working through third party distributors such as savings and credit cooperatives (SACCOs) and government and municipality contracts have less direct access to their customer base for warranty servicing and take-back programs, making collection logistics more challenging.

3.4 REGULATIONS AROUND SHS DISTRIBUTION AND COLLECTION

The off-grid solar sector in East and West Africa operates largely without extensive regulatory restrictions or guidance, putting both businesses and customers at risk. There is currently no equivalent to the Extended Producer Responsibility (EPR) guidelines that exist for product suppliers across Europe and North America. In Senegal, SHS distributors operate under an umbrella organization, the Council of Professionals of Renewable Energies of Senegal (*Conseil Patronal des Energies Renouvelables du Sénégal,* COPERES), but membership is optional. Generally, SHS businesses are regulated under the wider business and electricity policies. Besides the weak regulatory framework, there are agencies mandated to implement some international standards. The Uganda Solar Energy Association (USEA) is a watchdog for all its members, though membership is not mandatory. The Senegalese Standards Association (*Association Sénégalaise de Normalisation,* ASN) has set some SHS standards, however these are yet to be enforced. Similarly, there is little regulation of solar e-waste management collection, processing, or recycling by SHS distributors.

Increasingly, industry associations such as the GOGLA have organized at the regional level in an attempt to consolidate the fragmented sector, advocate for companies, and improve the business environment

for renewable energy companies - however, few protections exist at the customer level. Lighting Global certification, a global quality standard, is the primary benchmark for quality assurance, durability, and truth in advertising regarding product performance. However, little standardization exists in products across the market, the lack of which contributes to the challenge of developing efficient recycling infrastructure, especially around batteries. Products without Lighting Global certification provide no guarantee to customers on performance or quality, but despite industry efforts to educate consumers, few customers are aware of this shortcoming.

3.5 OPTIMIZING PRODUCT LIFESPAN: AFTER-SALES SERVICE AND WARRANTY PROGRAMS

The majority of companies interviewed provide warranty packages ranging from one to five years, with the exception of standalone PV panels, for which some companies provide a warranty of up to 25 years. Component-based warranties are often also available from the manufacturer. Under warranty protection, companies perform repairs and replace faulty system components at no cost, though some charge for local transport. In cases of system failure resulting from product misuse or failure outside the warranty period, companies will often repair the system for a fee. The companies interviewed indicated that they estimate the lifespan of their SHSs from 1.5 to 20 years, largely variable based on system size and cost. As a core requirement for Lighting Global certification, companies must offer a warranty for their products (Lighting Global, 2017). Similarly, GOGLA members are required to ensure that there are parts available locally for all replaceable SHS components. Warranty conditions vary widely company to company, after which repair costs are highly variable to the end user.

TABLE 4. WARRANTY PACKAGES AMONG SHS DISTRIBUTORS INTERVIEWED

	LENGTH (YEARS)			
	1-3	**3-5**	**5-10**	**10-25**
SHS Kit	13	2	N/A	N/A
PV Panel	N/A	N/A	2	5
Charge Control System	1	2	N/A	N/A
Battery	5	N/A	N/A	N/A

Often, companies will replace rather than repair faulty products, depending on local capacity. More established companies have call centers available for customer service. The ability to virtually diagnose issues helps the company identify whether the issue is warranty bound or not. Occasionally, third party technicians are hired by companies or by SHS owners for after-sales services that smaller companies cannot provide in-house.

A large portion of products replaced under warranty often do not have an actual technical issue, but this is not generally discovered until the unit has been returned to the manufacturer for diagnosis. Reasons customers return units include: 1) a defective unit under warranty, 2) a non-defective unit with a perceived problem (highly common), and 3) repossession due to non-payment on a SHS loan. This results in a large number of non-defective SHSs collected, which are often used as warranty replacement units or resold as "certified refurbished" at a lower cost.

> *"One of our biggest selling points is our ability to offer strong after-sales support because we have a team of over 300 technicians across different regions of the country on hand to troubleshoot and serve the customer as needed." - SHS Distributor*

"We sometimes train technicians to offer support to our partners who lack the capacity to offer after-sales service training to their agent network. For example, we recently were called to do a training of 60 technicians in Northern Uganda. We are also part of a team that is setting up a curriculum for solar energy technician training in partnership with Nakawa Vocational Center and GIZ" - SHS Distributor

Interviews with key SHS distributors concluded that most product performance issues were due to system overload, and thus attributed to consumer misuse. This misuse often occurs due to a lack of user guidelines available in local languages. Other companies reported system failures due to damaged wiring, which was often caused by customer tampering, and battery failure due to misuse. Batteries were often the initial point of system failure due to customer mishandling and longevity challenges.

Companies have few protocols to inform customers on product handling and repair after warranty expiration. Customer misuse within the warranty period has also led to additional cost burden to companies.

"Battery (performance) largely depends on the customer: If they don't charge it correctly, or if it spends a lot of time on the shelf without charge then it is more likely to get damaged and not work very well, or sometimes fail to work completely." - SHS Distributor

"If you have a product that the customer has fully paid for and then fails outside the warranty period, the customer may not take any action to have it repaired and may just throw it away. (The company) wouldn't know anything about it" - SHS Distributor

As in Uganda, where most companies are offering SHS on credit and after-sales services for repairs and warranty servicing are built into this pricing model, loan default rates hinder companies' capacity to ensure quality after-sales services to its entire customer base. Companies also face challenges in not being able to track PAYGO customer locations due to customer tampering and third-party faulty repairs. It was observed that PAYGO products are less common in Senegal, where only 1 of the 30 companies interviewed offered the service. Companies are also faced with the challenge of technicians who tamper with PAYGO systems, allowing customers to access solar energy without paying.

"People have found ways to cut the units open and tamper with the payment devices and get free access to solar, which is a challenge to business (and product performance)." -SHS Distributor

Customer misconceptions regarding the quality of replacement components also present challenges. Three companies stated that customers refused to provide faulty batteries to technicians for replacement, as they didn't believe the new battery replacement would perform.

3.6 REPLACEMENT REQUIRED: COMPANY TAKE-BACK PROGRAMS

Most companies offer take-back programs related to faulty components under warranty, but replacements are often subject to available stock in-country. If the part must be shipped from the manufacturer, wait times may be long. Return policies allow customers to return systems with faulty circuits within a limited time period. Companies can reuse salvaged parts from these systems.

More established companies have in-country diagnostics teams to analyze issues. In these cases, a centralized call center handles all customer service calls; local sales agents or technicians collect products for repair at a central location. The cost of transportation and parts replacement for problems requiring shipment to the original production facility (often overseas) is generally covered by the manufacturer. The cost of issues that are resolvable in-country is covered by the distributor. A

small percentage of SHS distributors are testing models of refurbishment and second use sales but have yet to fully resolve issues of quality assurance. As many devices are discovered to be non-defective upon diagnosis by the distributor or manufacturer, collection and refurbishment has the potential to resolve a large source of potential e-waste.

As most companies interviewed have been in operation for less than 10 years, which is the low end of expected lifespan for most systems, companies are just starting to think through take-back programs and more comprehensive repair services. For example, one SHS company indicated that they do not have a warranty or a take back program due to the trusted quality of their solar panels, and a lack of feedback from their early customers who acquired the products seven years back. However, they anticipate initiating the program in 2019 or 2020, when they expect their products to start developing mechanical issues.

Currently, the majority of take-back programs are customer-driven—the customer bears the cost of transport to return the product for replacement or upgrade. The following section outlines the economic and logistical challenges faced by companies seeking to take a more proactive role in product responsibility and e-waste management.

3.7 COMPANY-LED SOLAR E-WASTE MANAGEMENT

3.7.1 GEOGRAPHIC AND ECONOMIC CHALLENGES OF RURAL E-WASTE COLLECTION

Many SHS distributors lack in-house capacity to manage product collection at the end of products' life and report difficulty in identifying qualified partners to manage product collection for a fee. Solar companies distributing through third parties are unable to track their products after the point of sale, leaving the customer to bear the responsibility of finding a repair provider, which poses challenges around quality control of refurbished products. As SHS technology modernizes and the costs associated with embedded remote performance monitoring/GPS capacity decrease, the technology will become more widely available to SHS distributors and product tracking will become more accessible. However, this feature is currently limited to specific company product lines.

Government entities and banks do not readily part with the e-waste they generate, due to privacy and security concerns. This reluctance poses a challenge, as these entities can comprise a large portion of a company's customer base (CLASP 2019 Survey).

> *"Knowing the customer's exact location is a bit of a challenge. We have agents who sell product (across many communities) and keep moving from one area to another. We are trying to eliminate this challenge by developing strategies that can help the team track customer locations, through thorough agent documentation, and possibly acquiring a GPS tracker in the future." - SHS Distributor*

Despite these challenges, several companies interviewed reported that they have trained representatives from across SSA on proper e-waste management. After-sales services, which can help products outlive and outperform inferior merchandise, also offers companies an advantage when competing with lower-cost, poor quality merchandise.

Companies are in the early days of establishing branches and partnerships across SSA to process e-waste within the countries where it is generated. The industry has a long way to go to minimize the costly export of e-waste. The lack of recycling facilities that accept e-waste in the region, not specific to the solar industry, limits in-country processing capacity.

"Our goal is not to process e-waste collected from other (countries), but to have partners who can be empowered to handle e-waste locally in-country, so that whatever (salvage) value exists can be used to grow the local economy." - e-Waste Recycling Company

3.7.2 COMPETITION WITH POOR QUALITY PRODUCTS PROVIDING NO WARRANTY PROTECTION

SHS distributors report significant competition with other SHS suppliers of lower quality product, often Chinese-made, that appear similar but perform poorly, have a shorter lifespan, and offer no warranty protection. As these products are often sold at a slightly lower cost than a Lighting Global-certified product, they are purchased in higher volume and discarded after use. This presents a waste stream not currently managed by any direct supplier, compounding the collection issue.

"Currently it's not easy because solar panels look very similar even though the quality is quite different, and customers do not have available equipment or capacity to test the quality of a solar panel (before purchase). For example, in the market, it's common to buy a solar panel stated to provide 50 watts, but if you can test it, generally it's only 30 to 40 watts. But most of our customers cannot check this, and purchase the lowest cost option" - SHS Distributor

To address the challenge of counterfeit products, most companies have branded their products and ensure they are sold only in designated shops.

3.7.3 CHALLENGES IN SOURCING THIRD-PARTY E-WASTE MANAGEMENT SERVICE PROVIDERS

There is an ongoing challenge in sourcing suitable local recycling companies to handle the treatment of plastics, metals, cables, PV modules, and batteries, most of which are currently exported to processing hubs in the Middle East or Europe. Companies expressed concern about the limited capacity of local recycling companies as the volume of SHS product waste is rising.

"If you put into perspective the number of people currently adopting solar energy, the ability (as a company) to have control over e-waste is critical. We have 300,000 consumers today. That means that if we stopped selling today there will be 300,000 SHS components (panels, battery units, lights) that need to be disposed of in the next five years. (Given current company growth), we will soon be talking about a million SHS components that will need to be managed at end-of-life. We already have a partner in the region that disposes of and recycles our e-waste, but can they scale?" - SHS Distributor

Many companies indicated challenges around warehouse space limitations. Some indicated that they lack separate facilities to dispose of the waste products and end up storing e-waste alongside new products in a warehouse. In countries like Rwanda, there is an established system for disposing of waste products from solar systems and as a result some products, such as batteries, are less expensive, since companies do not incur costs for disposal management. As lithium-ion batteries pose challenges in disposal and recycling, they often incur higher costs, which are often passed on to the end user.

"We need a proper disposal (facility), separate from where we work, for collection prior to disposal. We stack batteries on pallets outside, and cables and panels are kept in boxes until collected." - SHS Distributor

3.8 A NASCENT MARKET ECOSYSTEM: E-WASTE MANAGEMENT SERVICE PROVIDERS

E-waste management is a relatively new challenge in the region. There are few formal separation and recycling practices due to rudimentary local collection and processing capacities. Existing waste

management company customers include local businesses, governments, and households who deposit waste at specific points, where it is collected and transported to a processing facility. Due to the lack of regulation around e-waste handling and processing, waste management companies are rarely obligated to follow standard protocols for e-waste management. Many companies charge an upfront processing fee based on volume, but do not differentiate types of waste. Waste management is often handled by the informal sector.

Materials collected from SHS distributors are typically segregated into scrap metal, batteries, and e-waste at a centralized collection point and transported accordingly. Several service providers separate aluminum and silica from the PV panels for their material resale value, but this mechanical separation capacity is not common in most markets. Batteries are often prioritized for their salvage value, capacity for refurbishment, and second use applications, but many waste processing plants lack capacity for recycling.

Demand for community collection centers for third party processing is increasing as individual distributors struggle to manage the economics of collection and handling of end-of-life products on their own (Manhart et al, 2018). Data protection and brand management will be an ongoing issue as e-waste service providers seek to increase waste stream volume to become economically viable.

Several leading SHS distributors in Uganda have in-house collection and sorting protocols in place. Components are warehoused and sorted by material type and disposed of by companies certified by the National Environment Management Authority (NEMA). NEMA is a semi-autonomous institution responsible for coordinating, monitoring, regulating, and supervising environmental management in Uganda. The agency spearheads the development of environmental policies, laws, regulations, standards, and guidelines and guides the Government on sound environmental management. However, due to the lack of local processing capacity, most components are still shipped to Europe for recycling and disposal.

3.8.1 OPPORTUNITIES FOR THE SOLAR E-WASTE MANAGEMENT INDUSTRY

Establishing stable e-waste supply channels with sufficient volume of materials, ideally with some salvage value, is the primary challenge local recycling companies must overcome to achieve profitability while supporting the off-grid solar sector. Several e-waste processing companies have developed partnerships with larger SHS distributors to test whether this can be realized, but the recycling infrastructure and government leadership required to execute on these agreements (e.g. consumer guidance on end-of-life product disposal provided upfront upon product sale, local community-based collection points, logistics for company collection and transport to processing plants, etc.) is still largely undeveloped.

While solar panels, batteries, and other system components have some salvage value, few local facilities have in-house capacity for processing. Materials such as silica and aluminum have second use applications in solar panel production and construction but must be separated and processed independently at high volume to be economically compelling. Several business models are being tested to optimize recyclability and refurbishment efforts, but this market segment needs further development before it can provide reliable economic opportunities. Opportunities exist around SHS product design-for-recyclability, but these modifications largely need to demonstrate cost-savings before being adopted by the industry due to companies' limited research and development budgets. While these product design initiatives are limited by companies' ability to invest in research and development, there is significant opportunity for third parties, such as Lighting Global, to provide guidance, recommendations, and incentives for material selection to improve recyclability. Several companies interviewed reported that they are partnering with other industry players at innovation centers across East Africa to explore and develop second use applications for components.

"We still have many years before this region is fully grid-connected, and with a growing population, e-waste management is necessary … The e-waste (recycling) sector generates a lot of reusable waste metals, which will be an (investable) opportunity over time." - E-Waste Recycling Company

3.8.2 CHALLENGES ENCOUNTERED IN SOLAR E-WASTE MANAGEMENT

Respondents reported that one of the biggest challenges they encounter is a lack of consumer awareness about e-waste management, leading to careless dumping of e-waste and environmental pollution. In addition to a lack of basic e-waste understanding, consumers will often adopt the lowest cost means of disposal available to them, which is compounded by the lack of e-waste management regulations at the municipal or national level.

Some companies auction their equipment to the informal sector rather than directly ensuring the equipment is properly disposed of, due to financial incentives. A lack of investment in communications to ensure community collection points are well established has also prevented companies from collecting a sufficient volume of e-waste. Staff turnover and retention at recycling centers also pose ongoing challenges. Recyclers mentioned that sometimes they employ staff and train them on e-waste management, but the staff tend to leave the company after a short time period.

Without a thriving commercial industry, research and innovation around e-waste management is largely underfunded. Because companies that have been licensed by NEMA or other environmental authorities are in competition with companies producing unlicensed and counterfeit materials, their profit margins are slim, leaving them little room to invest in improved facilities or state-of-the-art technology for in-country e-waste processing.

SECTION 4: KEY INSIGHTS ON SUSTAINABLE BATTERY MANAGEMENT IN UGANDA AND SENEGAL

Several suppliers are developing and manufacturing battery products for SHS applications, with cost and longevity as the leading factors influencing procurement. Batteries used in home energy storage are typically made with one of three chemical compositions: lead acid, lithium ion, or saltwater. Lithium ion batteries are a more appropriate storage solution because of their higher depth of discharge and longer lifespan. However, other battery types can be more affordable. Currently, lead acid batteries are the least expensive, are highly durable in challenging weather conditions, and most commonly used in rural off-grid areas. Without recycling facilities in place to manage waste, improper handling in salvage and collection efforts by the informal sector creates numerous health and social concerns.

4.1 SHS BATTERY MANUFACTURING AND DISTRIBUTION

Of the companies interviewed, only Chloride Exide Kenya, Chloride Exide Uganda, and Uganda Batteries Ltd. manufacture batteries. Chloride Exide Kenya is the largest manufacturer of batteries in the region, operating mainly through dealers. They have opened branches in Uganda and Tanzania and are currently seeking dealerships in Zambia, South Sudan, and Ethiopia. In addition to the centers in Nairobi, the company has trained third party technicians who install and maintain their batteries. The main end-users are homes, institutions, and businesses. None of these three manufacturers deal in new or emerging battery technologies, mainly because the cost of production is high and the retail price would be unaffordable for most customers.

Though SHS distribution companies are not pursuing many emerging battery technologies, companies did report that they use imported lithium ion batteries, which was not previously the case. Some companies are incorporating lithium ion technology to run larger equipment, as opposed to its more common use in small equipment. SHS companies are now using AGM and lithium ion-potassium batteries; the latter are a bigger component of SHS kits. SHS distributors who have not adopted lithium ion batteries report this is because they are still new on the market, have a slow distribution rate due to their high price, and people are unaware of how they function.

One battery supplier who assembles new lithium-ion ferro-phosphate batteries reported a high potential for lithium ion batteries in the market. The company also repurposes old lithium ion batteries by dismantling and testing each cell's functionality. The degraded cells are reworked and repackaged as a second life battery, then sold at a lower price. The company offers the opportunity to upgrade their batteries by increasing the number of cells, increasing amperage even after the battery purchased. The customer pays a fee for the upgrade that is lower than the cost of a new battery.

Battery manufacturers reported that they mainly produce lead acid type batteries. Vented lead acid batteries, which are serviceable, are popular in the market because of their low price and longer life, if well maintained. However, manufacturers are increasingly shifting to maintenance-free batteries, which are preferred in the market due to reduced electrolyte spillage.

4.1.1 SHS BATTERY PERFORMANCE VS. COST

Respondents reported that prices are lower when purchasing batteries from a dealer, compared to the factory. This is partly because manufacturers give discounts to dealers as an incentive to sell more batteries. The reported drivers of the market price of batteries included: costs related to production (such as power and raw materials, including lead, which is now a precious material); packaging costs; market forces, including demand, competition, and currency exchange rates. While lithium ion batteries

have a higher upfront cost, the technology lasts three to five times longer than lead acid batteries. Lithium ion batteries are also generally considered to be at their end-of-life at 75 to 80 percent discharge, which provides a window for second use application, though fluctuating battery performance at this level of discharge presents significant quality assurance challenges.

4.1.2 CORPORATE TAKE-BACK PROGRAMS AND END-OF-LIFE MANAGEMENT

Most companies interviewed have policies for disposal of batteries at the end of their life that allows customers to return the batteries for recycling within a period of two to four years in exchange for a discount on a new battery. Customers are informed about the policy at the point of sale and receive regular SMS reminders. These companies have facilities where batteries are stored before waste managers pick them up.

> *"For all our batteries, we take them back and recycle them. The most important thing is the lead in the battery. Clients are given a discount if they are buying a new one and leaving the old one behind." - Battery Manufacturer*

Other companies indicated that used batteries are collected and dumped with no clear recycling plans, except that acidic ones are neutralized. Some dumped batteries are picked up by individuals who take them away; the study respondents did not know for what the batteries were then used.

Since most off-grid systems will continue to rely on lead batteries, it is imperative that proper waste management protocols are established. There are few industry specific standards to mandate pollution control technology or limit emissions from lead battery recycling plants in Africa, though most countries have local regulations for lead battery recycling plant performance, technical and operational requirements (Gottesfeld et al., 2018). That being said, little recycling infrastructure is in place to encourage recycling at the local level.

Many companies, especially local companies that have supplied SHS products for 10 years or less, have not started thinking about disposal plans, highly concerning given the negative environmental impacts that e-waste can potentially create when not properly disposed. This situation is worsened by limited data regarding what users do with SHS products that have failed or reached the end of their life.

Some respondents reported that enterprising individuals in communities often purchase used batteries from households and recycle them for secondary use. Most companies do not charge their waste managers for taking batteries that have reached end-of-life as they do not attach any economic value to them, though other products are harvested for spare parts and used in repairs before recyclers handle the leftover scrap.

Farther down the market's time horizon is lithium ion battery end-of-life management. As second use applications of lithium ion batteries are not appropriate for SHS due to performance limitations, most reuse applications include disassembly and the recapture of valuable metals. Current lithium ion battery recycling processes are energy intensive but efficient methods are being tested and piloted, primarily in Europe and the Middle East (Shi, Chen, & Chen, 2018).

While challenges exist, increased battery recycling could contribute to sustainable job creation, improving the safety of waste treatment employment, and decouple economic growth from environmental degradation. Processing of e-waste could generate more than 32 times more jobs than are required for traditional disposal operations (Sampson, 2015).

SECTION 5: CUSTOMER PERCEPTIONS ON SOLAR E-WASTE: KEY INSIGHTS FROM HOUSEHOLD SURVEYS

5.1 OVERVIEW

5.1.1 SURVEY POPULATION SAMPLE

In the spring of 2019, the study team interviewed 320 Ugandan households across 40 villages in eight districts for the household survey. The questions consisted of baseline demographics and questions related to the household use of SHS and treatment of e-waste. Each household had an average of five occupants (mean and median value); 75 percent owned their homes. Of the respondents, 93 percent attended school at some point in their lives, with 58 percent having completed some or all of primary school, 36 percent having completed some or all of secondary school, and 6 percent having tertiary or university level education. When asked about employment, 56 percent reported running a business (either by themselves or with others) within the last month and 28 percent reported being employed by someone outside of the household. Regarding land, 86 percent of households owned land, 48 percent of households produced and sold crops, and 9 percent produced and sold animal products in the 12 months prior to the survey.

5.1.3 SHS CATEGORIZATION

Respondents were asked the brand of their SHS and grouped based on the product(s) they owned. Of the 320 respondents, 160 owned SHS; of these, 58 percent owned name-brand systems and 42 percent owned off-brand systems. For this analysis, the respondents were divided into two categories: those who own name-brand products (Fenix, SolarNow, BBOXX, AZURI, d light, and M-KOPA) and those who own off-brand products.

5.1.3 CATEGORIZATION OF DISPOSAL BEHAVIOR

One of the critical survey questions was, "If your SHS/component stopped working today, what would you do with it?" Several different answers were provided, which were divided into "responsible" disposal behaviors and "harmful" behaviors (Table 5). Responsible behaviors removed the old components from the environment and/or placed them in an e-waste specific waste stream. Harmful behaviors allow for the components to infiltrate the environment (including ending up in waste streams that do not have procedures for dealing with the chemicals contained in these materials).

TABLE 5. CATEGORIZATION OF DISPOSAL BEHAVIORS

RESPONSIBLE	HARMFUL
Recycled • Upcycled • Picked up by supplier	Thrown away, discarded • Burned • Placed in storage (house or shed/structure) • Sold • Trade in for new component (to third party vendor, not direct supplier) • Trade in for cash (third party vendor) • Picked up by scrap vendor

5.2 KEY HIGHLIGHTS

- Owners of name-brand SHS paid 40 percent more than off-brand for their SHS.

- Owners of name-brand SHS are 61 - 82 percent more likely to dispose of e-waste responsibly. This number holds when controlling for other demographic factors, such as income, overall wealth, business ownership, and land ownership.
- When SHS equipment is broken, 85 percent of name-brand and 91 percent of off-brand system owners sought to repair the system.
  - The majority of name-brand owners took their SHS to the equipment service provider (62 percent). Owners of off-brand SHS typically went to a repair shop (73 percent).
- Owners of name-brand SHSs are more aware of profit opportunities associated with old batteries; 83 percent have received cash or a discount for return of broken equipment, compared to 44 percent of off-brand owners.
- Half of all respondents are not aware of any dangers associated with storing old SHS equipment in or near their home. No difference was found between name-brand owners, off-brand owners, and respondents without solar.
- Even when broken, SHS owners place a high value on their equipment: 200,000 UGX ($55) for name-brand and 100,000 UGX ($27) for off-brand. SHS owners would utilize an e-waste recycling/disposal center for an incentive based on travel distance:
  - 10,000 UGX ($3 USD) for a center less than 10 km away, or
  - 20,000 UGX ($6 USD) for a center between 15 and 25 km away.

5.3 HOUSEHOLD STUDY RESULTS

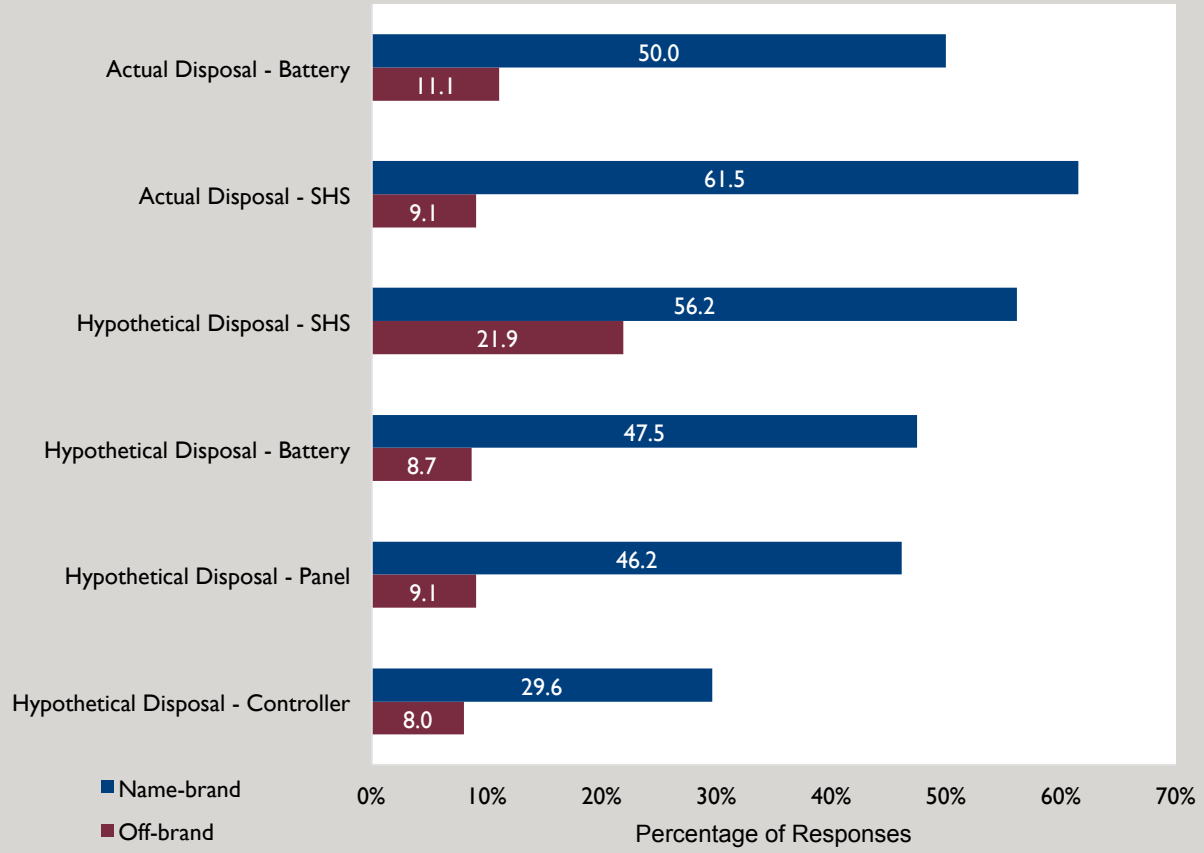
5.3.1 DISPOSAL BEHAVIOR

When asked, "If your SHS stopped working today, what would you do with it?" Respondents who owned name-brand SHS were more likely to respond with a responsible disposal behavior than owners of off-brand equipment in (56 percent vs. 22 percent respectively). This pattern held when respondents were asked the same question in relation to specific pieces of SHS equipment, including batteries, panels, and controllers.

Respondents were asked, "When your SHS stopped working, what did you do?" Only 24 had experienced an SHS breakdown (13 owners of name-brand systems and 11 owners of off-brand systems). Most repaired the broken equipment in some way. Owners of name-brand equipment were most likely to take the equipment to a service provider for repair (62 percent). Owners of off-brand equipment were more likely to take it to a repair shop (73 percent).

FIGURE 1. SURVEY RESULTS: ACTUAL AND HYPOTHETICAL DISPOSAL BEHAVIORS*

Percentage of Responsible SHS Component Disposal



**This graph includes data from Ugandan households that answered the question, "If you had to replace [SHS component], what would you do with it?" The answers to survey questions for actual disposal behavior were collected from Ugandan households that experienced an SHS equipment breakdown, posing the question, "When your [SHS component] stopped working, what did you do?" For actual disposal behavior, 24 households responded in regard to the SHS as a whole and 30 responded in regard to the battery. For the hypothetical behavior, 153, 126, 157, and 52 households responded for SHS, battery, panel, and controller respectively.*

When asked about a battery breakdown, owners of name-brand equipment were most likely to have it picked up/fixed by the supplier or store it in their home (50 percent and 33 percent respectively). Off-brand owners typically had it picked up by a scrap vendor or store it in- their home (33 percent and 22 percent respectively). Owners of name-brand equipment were also more aware of profit opportunities associated with old batteries; 83 percent turned in their broken equipment for cash or a discount. Of off-brand equipment owners, 56 percent did not profit from disposing of their battery and were not aware of any way to make a profit. The remaining 44 percent of off-brand owners received either cash or a discount for their old equipment.

5.3.2 UNDERSTANDING OF SAFETY AND ENVIRONMENTAL RISKS

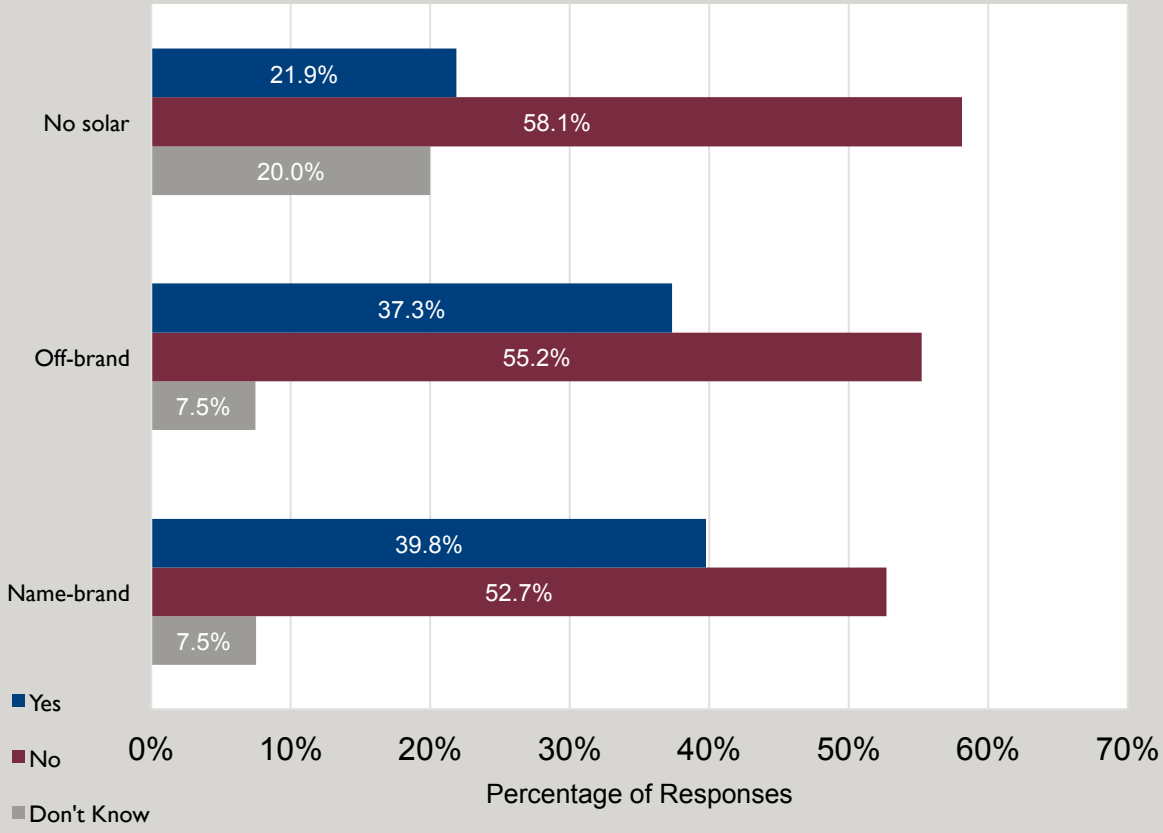
After inquiring about disposal behavior, the survey asked respondents "Is it dangerous to store an old SHS (or piece of SHS equipment) in or near your home?" The possible reasons for the danger are shown in Table 6. Most respondents were not aware of any dangers associated with storing old devices

within the household. This pattern held regardless SHS system ownership and was also true for owners of solar lanterns. Just below 40 percent of respondents who had SHS responded that it is dangerous to store an old SHS in or near the home (this number was 22 percent for those without SHS). About half of SHS owners knew that storing old batteries in or near the home is dangerous; 60 percent of respondents who did not own an SHS knew of this danger.

TABLE 6. CATEGORIZATION OF SAFETY AND ENVIRONMENTAL RISKS

WHY IS IT DANGEROUS TO STORE AN OLD SHS IN OR NEAR YOUR HOME?
Acid in the battery is not safe
Dangerous to children
Cancerous
Emits fumes
Can break and cut someone
Causes disease/sickness
Affects soil fertility
Contains harmful chemicals
Electric current could burn someone
Battery could explode
It may be poisonous
Other

FIGURE 2. SURVEY RESULTS: EVALUATION OF DANGERS ASSOCIATED WITH SHS COMPONENTS BY OWNER TYPE
Is it dangerous to store an old solar home system in or near your home?



5.3.3 PREDICTORS OF DISPOSAL BEHAVIOR

Using the survey responses collected, the research team developed a regression model to examine if household disposal behavior for e-waste can be predicted by other household attributes, including: ownership of name-brand vs. off-brand SHS, wealth, ownership of land, ownership of businesses, education level, and ownership of other electronic devices (such as smartphones, TVs, and computers).

Surprisingly, respondents that replied "yes" to the question "Is it dangerous to store an old SHS/SHS equipment near/in your home" do not appear to be any more likely to dispose of e-waste responsibly. This may be due to a lack of understanding as to what the proper ways to dispose of e-waste are, but respondents were not asked to indicate the correct way to dispose of SHS equipment and other e-waste. This was observed for SHS, battery, and panel disposal.

For both overall SHS and battery disposal, the total household wealth, business ownership, and land ownership do not appear to have any relationship with responsible behavior. SHS owners with high incomes are no more likely to exhibit responsible disposal behaviors than those with low incomes. A few household attributes do appear to make responsible behavior more likely, specifically owning a

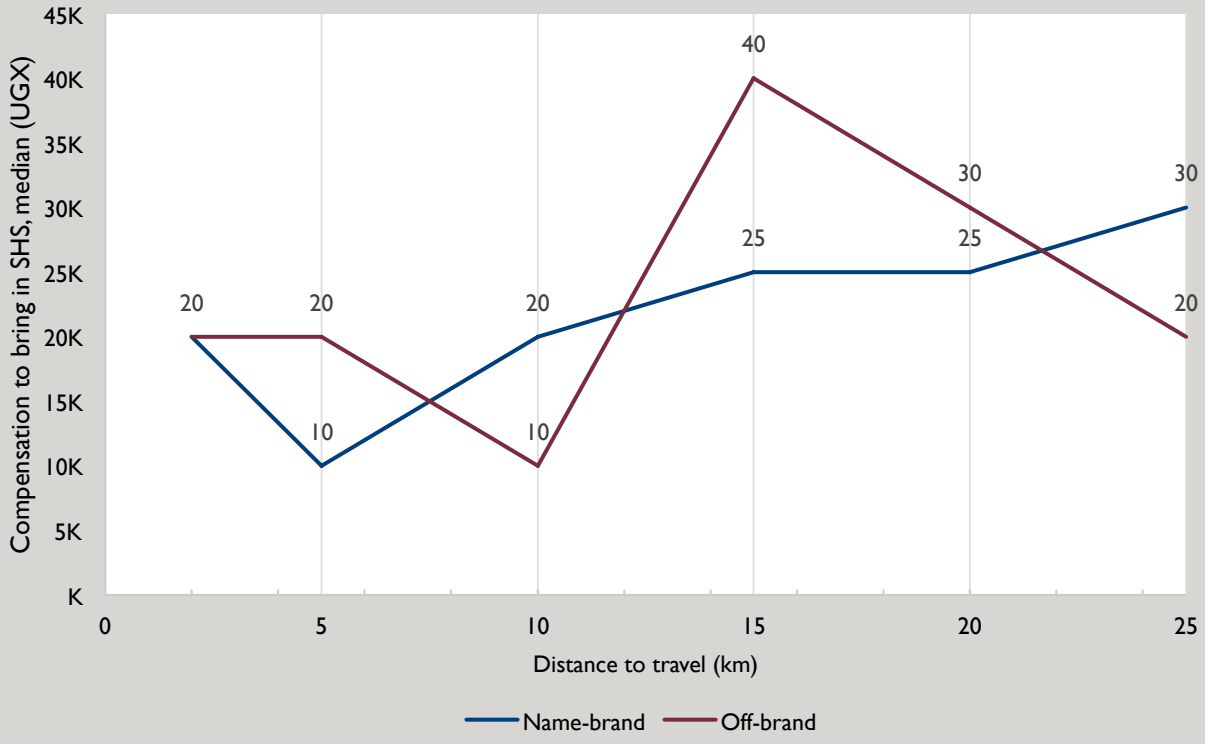
name-brand SHS, having a university level education, and ownership of other high-value electronic devices, though this last relationship is very small. Having a university-level education is the most significant indicator of responsible disposal behavior, followed by owning a name-brand SHS. Disposal behavior for panels was similar to SHS and battery disposal.

5.3.4 E-WASTE INCENTIVES

To determine good incentives for properly disposing of SHS equipment and other e-waste, survey respondents were asked questions to understand what amount of money would motivate them to return a broken component to a disposal center at distances varying from 2 to 25 km. The median solar user would ask for 10,000 UGX ($2 USD) as compensation for travel to a recycling center 2 to10 km away, regardless of brand ownership. For recycling centers between 15 and 25 km away, both name brand and off-brand owners would ask for compensation of 20,000 UGX ($5 USD). Figure 3 shows that the amount respondents would have to be compensated to return a broken component increased with distance to a disposal center.

The maximum amount requested was 300,000 UGX ($82 USD) and was requested only once. For most distances, the maximum compensation requested was 100,000 UGX ($27 USD). Analysis of the responses by wealth quartile revealed no consistent difference between groups. These results could be used to inform the design of disposal center locations and possible incentives.

FIGURE 3. MEDIAN COMPENSATION REQUIRED TO RETURN SHS PRODUCT TO DESIGNATED E-WASTE CENTER



Note: [1]SHS owners were asked questions to understand what amount of money would motivate them to return a broken component to a disposal enter. Respondents were asked: "If you took a broken component to a disposal center located [randomly assigned distance] km away, what amount of payment would motivate you to take the broken component to the disposal center? Please think through the costs that you might incur to travel this distance, including time." The distance the respondent was asked to consider was randomly assigned to be either 2, 5, or 10 km away. Subsequently, the respondents were asked a similar question, but the randomly chosen distance was set

at either 15, 20, or 25 km away from the disposal center. Responses from 107 SHS owners are reflected in this graph. For the first three days of data collection, several enumerators did not explain the question fully to respondents (i.e., they did not explain that respondents should think ONLY about the compensation for time and travel, not the value of the component/SHS they take). Hence, the analysis in this section drops the data from the first three days of data collection.

5.3.5 SHS COST AND END-OF-LIFE VALUE

Respondents who paid full price at the time of purchase paid a median of 550,000 UGX ($150 USD) for name-brand systems and 330,000 UGX ($90 USD) for off-brand systems. Only owners of name-brand systems purchased their equipment through a lease/hire purchase program; these respondents paid a median of 745,000 UGX ($204 USD) overall. The fact that all respondents with off-brand systems paid up front in full may be a factor of the lower system cost or may be because the lease/hire purchase option was not available.

When asked how much their SHS would be worth if it were broken, many respondents placed a high value on their equipment, including some respondents that did not currently own SHS. Owners of name-brand systems typically valued their broken SHS higher than owners of off-brand systems (median of 200,000 UGX ($55 USD) vs. 100,000 UGX ($27 USD)). Surprisingly, 16 percent of name-brand owners valued their system at less than 10,000 UGX ($3 USD). Only 5 percent of off-brand owners responded the same.

When asked about individual pieces of SHS equipment, responses varied. Name-brand owners typically valued a broken battery higher than off-brand owners (median of 50,000 UGX ($14 USD) vs. 30,000 UGX ($8 USD)). The value placed on a broken panel was the same for both categories (median of 50,000 UGX ($14 USD)). Off-brand system owners placed a higher value on a broken controller than the name-brand owners (median of 20,000 UGX ($6 USD) vs. 5,000 UGX ($1.50 USD)). In addition, 57 percent of name-brand owners placed the value of a broken controller at less than 10,000 UGX ($3 USD), while 30 percent of off-brand owners thought the same.

SECTION 6: BUILDING AN E-WASTE MARKET ECOSYSTEM: GOVERNMENT, INDUSTRY AND DONOR RECOMMENDATIONS

INDUSTRY RECOMMENDATIONS

- **Business Model Innovation and Testing**: Given the nascent e-waste market and lack of waste management infrastructure in the region, the supply chain for e-waste recycling is in the early days of development and demand is high for SHS distributor and recycling company matchmaking. Incredible opportunity exists to streamline this supply chain, but various business models will need to be supported and tested to optimize the economics, with a focus on inefficiencies in device collection, refurbishment, and replacement, under current warranty and take-back programs.
- **Industry Data Collection**: The provision and tracking of reliable data on end-of-life product management and e-waste flow volumes will be critical in informing longer-term investment in programs that address solar e-waste at a systemic level. These data should focus on past, current, and predictive future volumes to best inform investment decisions.
- **Last-Mile Incentive Schemes**: Given the nature of rural distribution, initial subsidization or incentive schemes may be necessary to reach last-mile customers. Currently, the transport burden generally lies on the customer to return end-of-life products to a company collection facility, if a take-back program exists. Little incentive or guidance on return or proper disposal is currently provided.
- **Product Design for Recyclability**: Manufacturing and distribution companies will need to explore waste reduction strategies that can be employed at the early stages of SHS design and manufacturing to emphasize design for ease of recycling at end-of-life. Given the additional investment in product research and development required, this will not likely be adopted broadly until the cost burden of waste management hits a critical point. However, several industry leaders are taking steps in this direction with waste-minimizing design innovations.
- **Consumer Education and E-waste Literacy**: Most SHS customers have little knowledge of proper disposal of their products. Companies could play a key role in responsible product management by incorporating basic end-of-life disposal guidance into the information provided at the point of sale and through after-sales services. Enhance strong consumer feedback mechanisms to address user complaints, including issues related to system failures, performance fluctuations, and refurbished product quality assurance.
- **Sustainable Battery Management**: As the industry will continue to pursue battery solutions that provide SHSs at the lowest cost to the consumer, overall lifetime costs to the consumer and company need to be considered in battery selection, collection, and disposal, with a focus on product lifespan and recyclability.

DONOR AND GOVERNMENT RECOMMENDATIONS

- Regulatory guidance must be established across the region to set a baseline of product responsibility standards for manufacturers, distributors, and waste management companies. Third party implementing partners (such as SOFIES Group) are currently supporting the early stage development of e-waste legislation across East Africa, and more stringent guidance will only assist the industry in the future.
- Opportunities exist around SHS product design-for-recyclability, but these modifications largely need to also demonstrate cost-savings before being adopted by the industry, due to limited corporate research and development budgets. While these product design initiatives are limited by internal investment by companies, there is significant opportunity for third parties, such as Lighting Global, to provide guidance, recommendations, and incentives for material selection to improve recyclability.
- Develop incentives to increase and enhance local e-waste recycling facilities, especially for lithium battery recycling. Developing local capacity will depend on sound business models of e-waste companies, the establishment of stronger supply channels will need to be established to source sufficient material volume for economic viability.
- Strengthen public-private partnerships aimed at increasing investment and expand government funding to attract private investment. The private sector can accelerate investment in both high quality SHS and establish recycling plants for SHS e-waste management. Governments can support this work by creating an enabling policy environment and actively communicating with the private sector.
- Support the establishment of extended producer responsibility as a business culture, including the following industry trends:
  - Develop products that can be easily maintained and repaired and ensure spare components are locally available;
  - Develop strategies to take back faulty products and source local recycling capacity in-country;
  - Build partnerships with other manufacturers of electronic products to share the cost of collection, repair, transportation, dismantling, and recycling; and
  - Avoid the use of hazardous substances in the production and composition of SHS and battery technologies, enhancing product design-for-recyclability whenever possible.

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APPENDIX A: COMPANY STAKEHOLDER INTERVIEWS: DETAILED NOTES

RESEARCH STUDY STAKEHOLDER LIST

Solar Home System Distributors

1. Africa Energy (Senegal)
2. AxEnergie (Senegal)
3. Azuri (Multi-country)
4. Baobab+ (Multi-country)
5. Barefoot Power (Uganda)
6. BBOXX (Multi-country)
7. Beta Energy (Senegal)
8. D.Light (Multi-country)
9. Davis & Shirtliff (Uganda)
10. Dura Energy (Senegal)
11. Elektron (Senegal)
12. Energeco Afrique (Senegal)
13. Fenix International (Multi-country)
14. Green Advocacy Ghana (Ghana)
15. Lagazel (Senegal)
16. Leser (Senegal)
17. M-KOPA (Multi-country)
18. Matenergy (Senegal)
19. Mobisol (Multi-country)
20. New Sun (Uganda)
21. NRJ Solaire (Senegal)
22. Opes Solutions (Multi-country)
23. Performance Solaire (Senegal)
24. Power Trust (Uganda)
25. Satech (Senegal)
26. Schneider Electric (Multi-country)
27. Sen Technologie Power (Senegal)
28. Sercom (Senegal)
29. Solantis (Uganda)
30. Solar Energy for Africa (SEFA) (Uganda)
31. SolarNow (Uganda)
32. Soleil Eu Vive (Senegal)
33. Solibrium (Kenya)
34. SOS Energy (Senegal)
35. Sud Solar (Senegal)
36. Sunna Design (Senegal)
37. Technologies du Futur (Senegal)
38. TCI Solar (Senegal)
39. Total (Multi-country)
40. Touba Solar Rama (Senegal)
41. Trans-African Supply Services (TASS) (Uganda)
42. Uganda Solar Energy Association (Uganda)
43. UltraTec (Uganda)
44. Village Energy (Uganda)
45. Village Power (Uganda)
46. Vitale (Senegal)
47. Water & Pumps International (Uganda)
48. Zola Electric (Multi-country)

E-Waste Recycling Companies

1. African Recycling Services (ARESE) (Senegal)
2. Asante Waste Management (Uganda)
3. Chilambo General Traders (Tanzania)
4. Enviroserve (Kenya)
5. Enviroserve (Rwanda)
6. Fassaly Dufoncoer (Independent e-waste recycler) (Senegal)
7. Ntinda XXX (Independent battery recycler) (Uganda)
8. Pape Claudel (Independent e-waste recycler) (Senegal)
9. Paul Mpelerwe (Independent battery recycler, Uganda)
10. Phenix Recycling (Kenya)
11. Recycla International (XXX)
12. Scrap Center Uganda (Uganda)
13. WEEE Centre (Kenya)

SHS Battery Distribution Companies

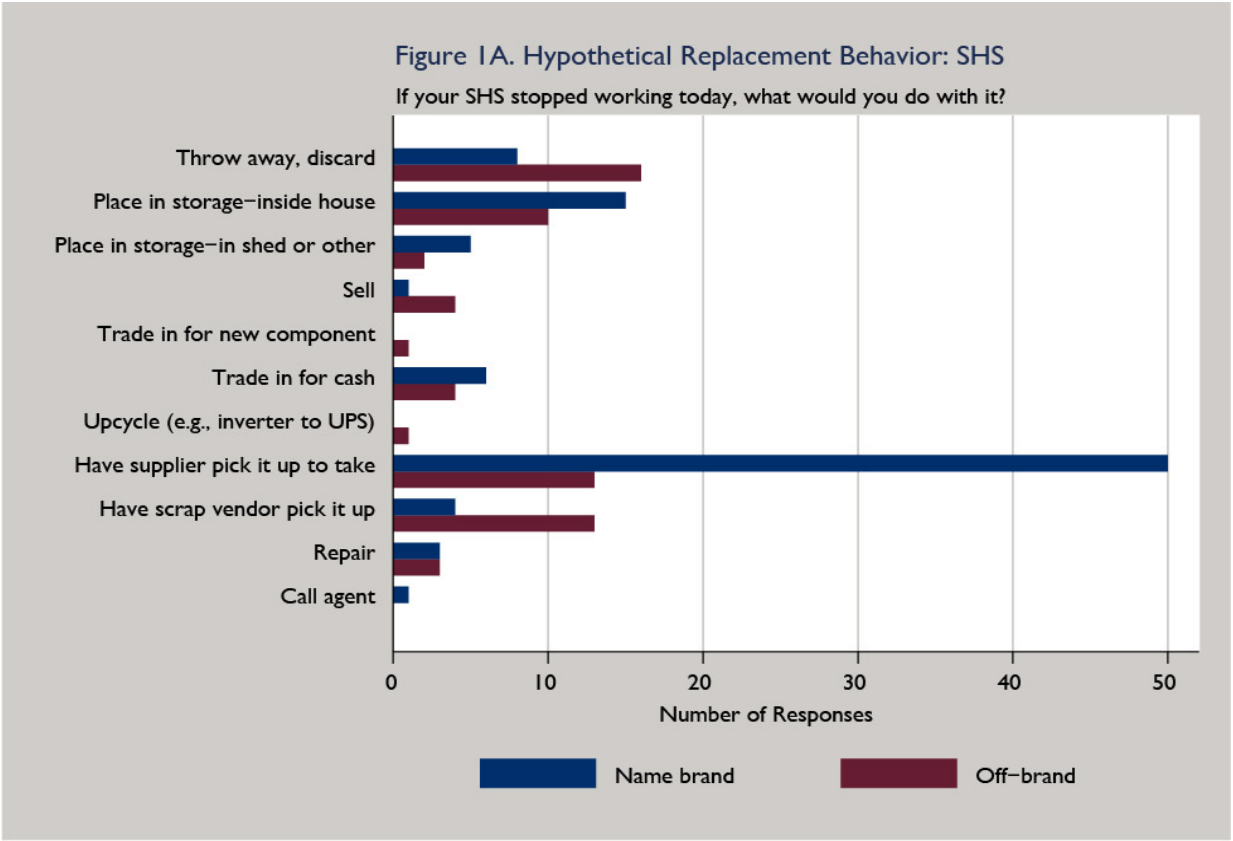
1. Chloride Exide Kenya (Kenya)
2. Chlorida Exide Uganda (Uganda)
3. Uganda Battery Ltd (Uganda)

APPENDIX B: HOUSEHOLD SOLAR ELECTRONIC WASTE SURVEY: DETAILED RESULTS

SECTION 1. WHERE DO PEOPLE COMMONLY DISPOSE OF PRODUCTS AT END-OF-LIFE?

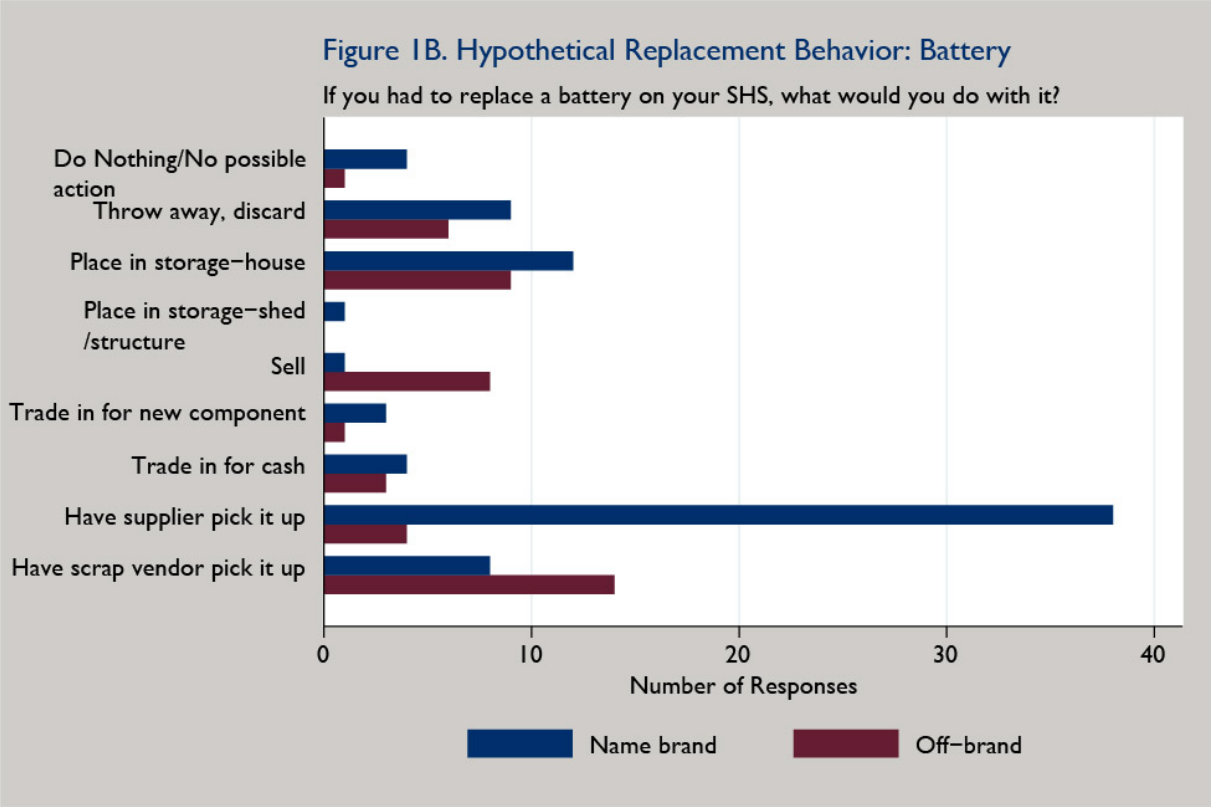
A. SHS

IF YOUR SHS STOPPED WORKING TODAY, WHAT WOULD YOU DO WITH IT?	OWNERS OF NAME-BRAND SHS		OWNERS OF OFF-BRAND SHS	
	Freq.	%	Freq.	%
Throw away, discard	8	8.6	16	23.9
Place in storage-inside house	15	16.1	10	14.9
Place in storage-in shed or other structure	5	5.4	2	3.0
Sell	1	1.1	4	6.0
Trade in for cash	6	6.5	4	6.0
Have supplier pick it up to take away	50	53.8	13	19.4
Have scrap vendor pick it up	4	4.3	13	19.4
Repair	3	3.2	3	4.5
Call agent	1	1.1	0	0.0
Trade in for new component	0	0	1	1.5
Upcycle (e.g., inverter to UPS)	0	0	1	1.5
Total	**93**	**100**	**67**	**100**

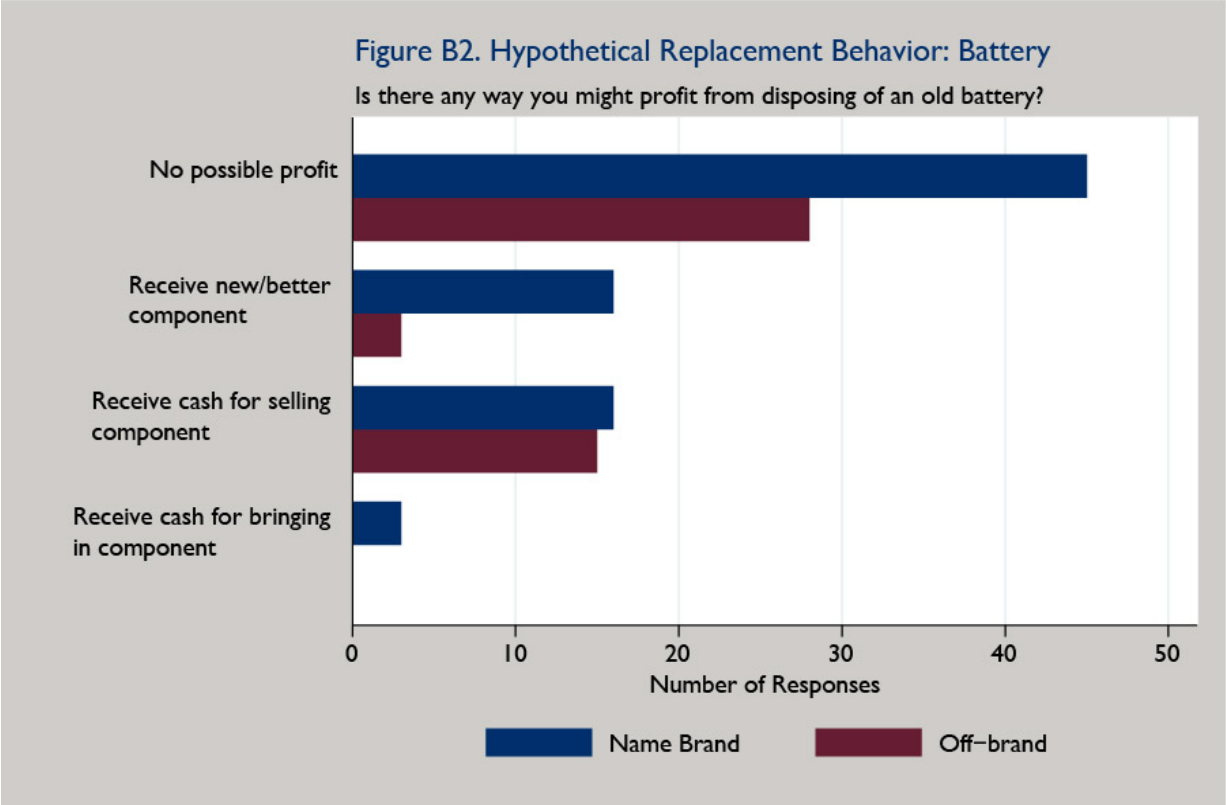


B. BATTERY

IF YOU HAD TO REPLACE A BATTERY ON YOUR SHS, WHAT WOULD YOU DO WITH IT?	OWNERS OF NAME-BRAND SHS		OWNERS OF OFF-BRAND SHS	
	Freq.	%	Freq.	%
Do Nothing/No possible action	4	5.0	1	2.2
Throw away, discard	9	11.3	6	13.0
Place in storage-house	12	15.0	9	19.6
Place in storage-shed/structure	1	1.3		0.0
Sell	1	1.3	8	17.4
Trade in for new component	3	3.8	1	2.2
Trade in for cash	4	5.0	3	6.5
Have supplier pick it up to take away o	38	47.5	4	8.7
Have scrap vendor pick it up	8	10.0	14	30.4
Total	**80**	**100**	**46**	**100**

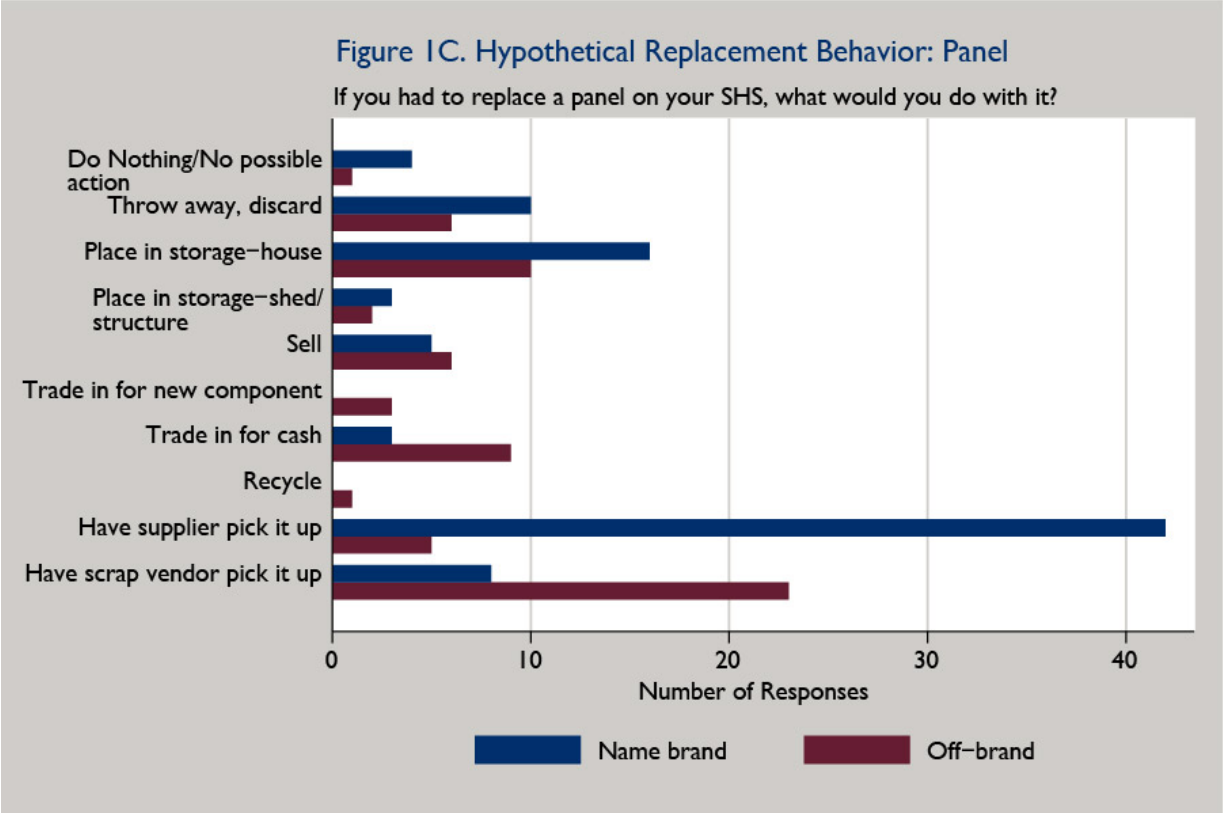


IS THERE ANY WAY YOU MIGHT PROFIT FROM DISPOSING OF AN OLD BATTERY?	OWNERS OF NAME-BRAND SHS		OWNERS OF OFF-BRAND SHS	
	Freq.	%	Freq.	%
No possible profit	45	56.3	28	60.9
Receive new/better component for discount	16	20.0	3	6.5
Receive cash for selling component	16	20.0	15	32.6
Receive cash for bringing in component	3	3.8	0	0.0
Total	**80**	**100**	**46**	**100**

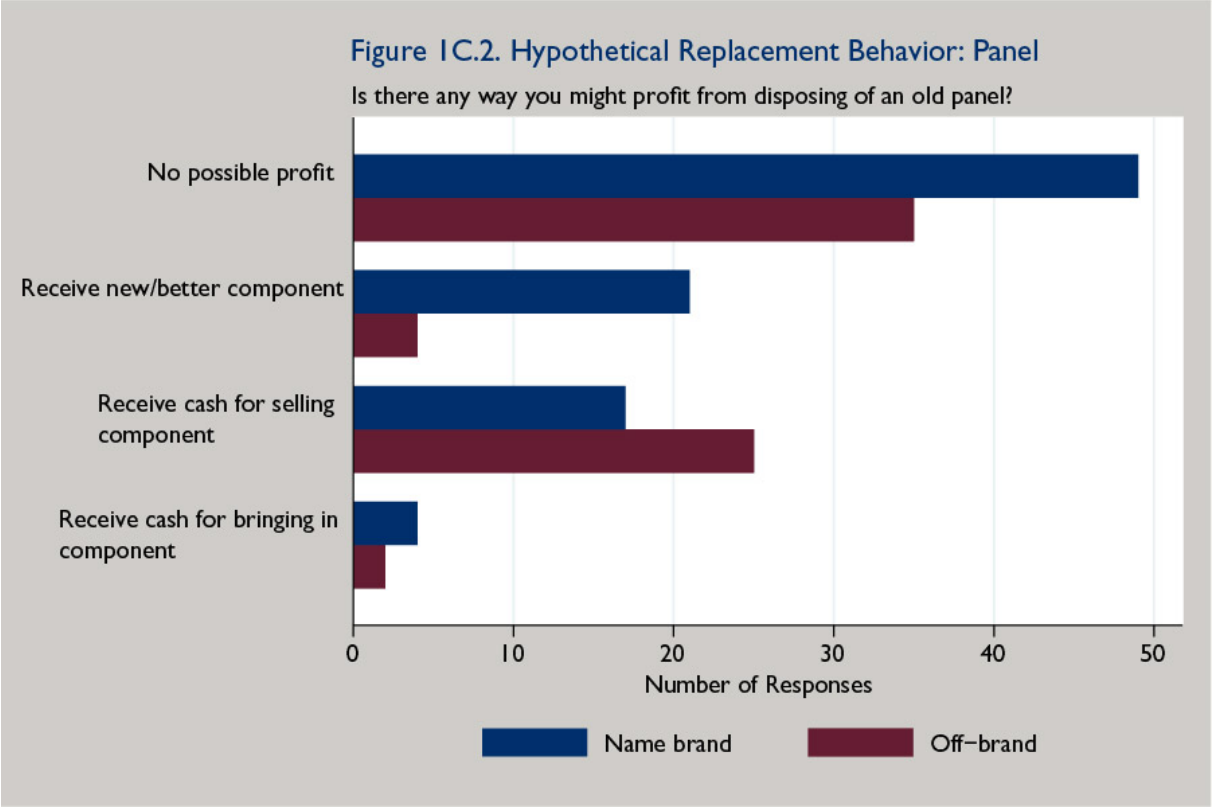


C. PANEL

IF YOU HAD TO REPLACE A PANEL ON YOUR SHS, WHAT WOULD YOU DO WITH IT?	OWNERS OF NAME-BRAND SHS		OWNERS OF OFF-BRAND SHS	
	Freq.	%	Freq.	%
Do Nothing/No possible action	4	4.4	1	1.5
Throw away, discard	10	11.0	6	9.1
Place in storage-house	16	17.6	10	15.2
Place in storage-shed/structure	3	3.3	2	3.0
Sell	5	5.5	6	9.1
Trade in for cash	3	3.3	9	13.6
Have supplier pick it up to take away o	42	46.2	5	7.6
Have scrap vendor pick it up	8	8.8	23	34.9
Trade in for new component	0	0.0	3	4.6
Recycle	0	0.0	1	1.5
Total	**91**	**100**	**66**	**100**

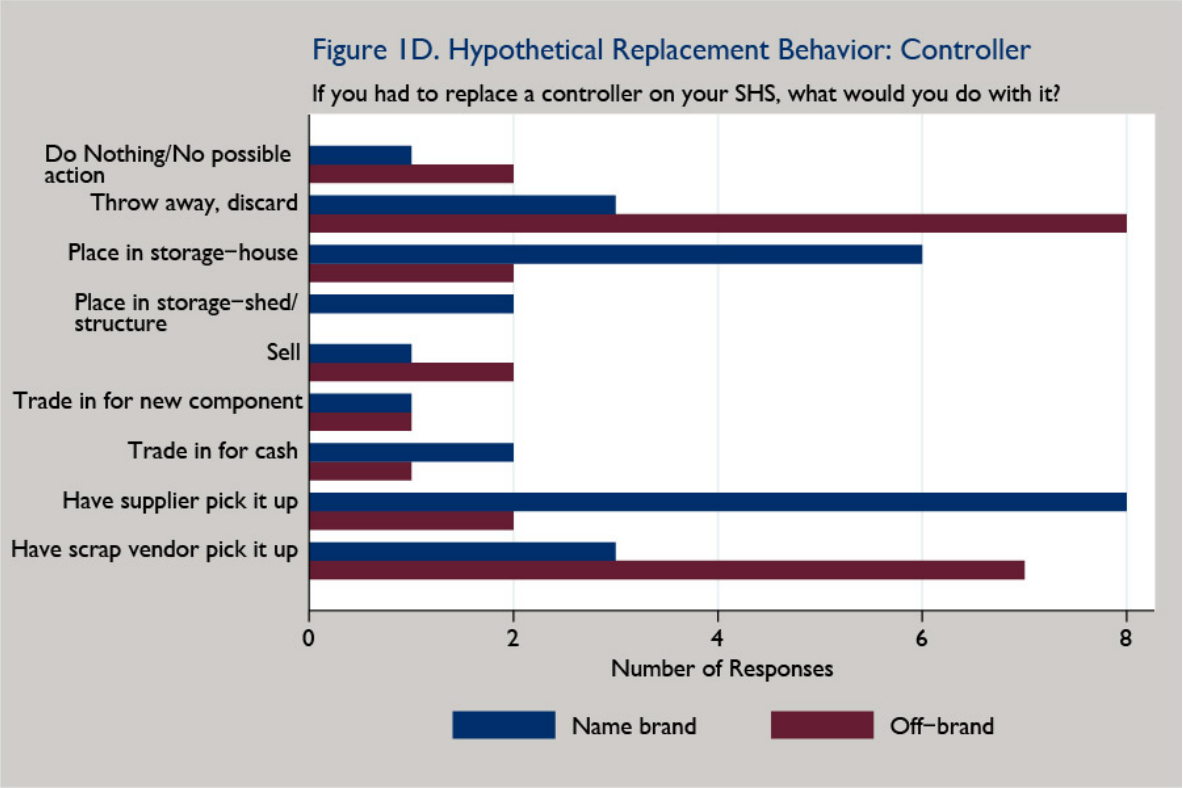


IS THERE ANY WAY YOU MIGHT PROFIT FROM DISPOSING OF AN OLD PANEL?	OWNERS OF NAME-BRAND SHS		OWNERS OF OFF-BRAND SHS	
	Freq.	%	Freq.	%
No possible profit	49	53.9	35	53.0
Receive new/better component for discount	21	23.1	4	6.1
Receive cash for selling component	17	18.7	25	37.9
Receive cash for bringing in component	4	4.4	2	3.0
Total	**91**	**100**	**66**	**100**



D. CONTROLLER

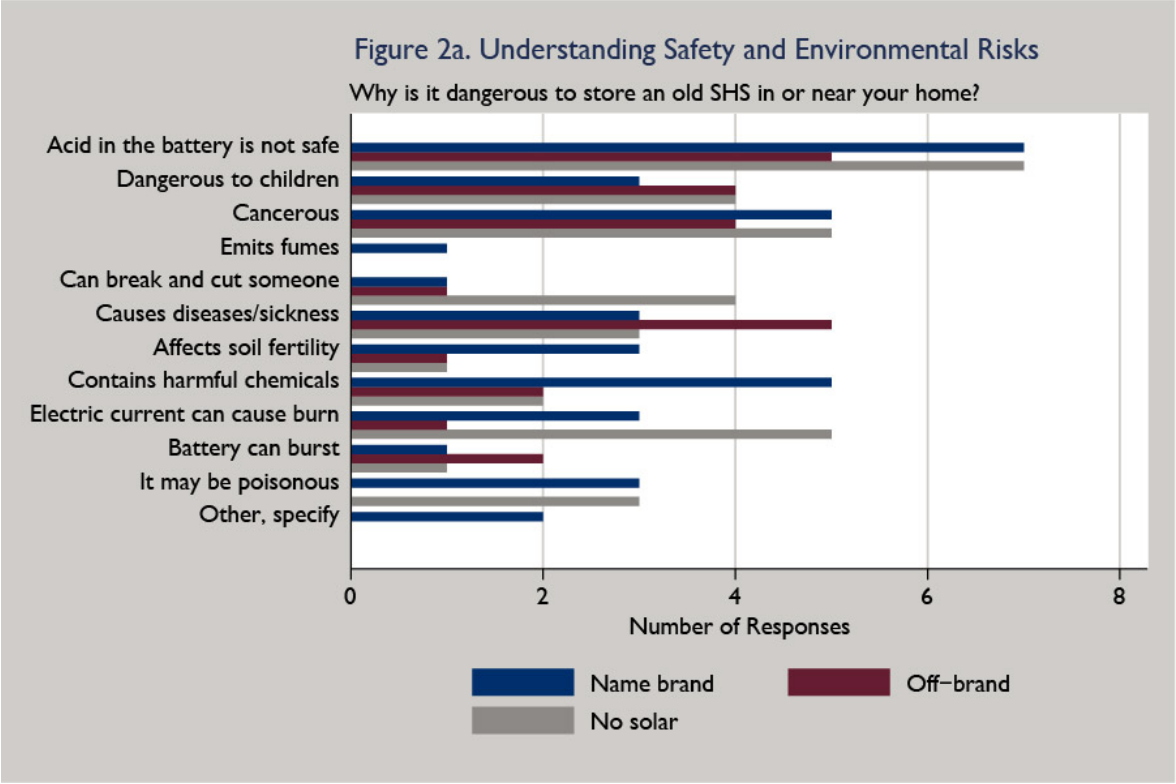
IF YOU HAD TO REPLACE A CONTROLLER ON YOUR SHS, WHAT WOULD YOU DO WITH IT?	OWNERS OF NAME-BRAND SHS		OWNERS OF OFF-BRAND SHS	
	Freq.	%	Freq.	%
Do Nothing/No possible action	1	3.7	2	8.0
Throw away, discard	3	11.1	8	32.0
Place in storage-house	6	22.2	2	8.0
Place in storage-shed/structure	2	7.4	0	0.0
Sell	1	3.7	2	8.0
Trade in for new component	1	3.7	1	4.0
Trade in for cash	2	7.4	1	4.0
Have supplier pick it up to take away o	8	29.6	2	8.0
Have scrap vendor pick it up	3	11.1	7	28.0
Total	**27**	**100**	**25**	**100**



SECTION 2. WHAT IS THE UNDERSTANDING ON SAFETY AND ENVIRONMENTAL RISKS?

A. SHS

WHY IS IT DANGEROUS?	OWNERS OF NAME-BRAND SHS		OWNERS OF OFF-BRAND SHS		HOUSEHOLDS WITHOUT SOLAR	
	Freq.	%	Freq.	%	Freq.	%
Acid in the battery is not safe	7	18.92	5	20.0	7	20.0
Dangerous to children	3	8.11	4	16.0	4	11.4
Cancerous	5	13.51	4	16.0	5	14.3
Emits fumes	1	2.7	-	-	-	-
Can break and cut someone	1	2.7	1	4.0	4	11.4
Causes diseases/sickness	3	8.11	5	20.0	3	8.6
Affects soil fertility	3	8.11	1	4.0	1	2.9
Contains harmful chemicals	5	13.51	2	8.0	2	5.7
Electric current can burn someone	3	8.11	1	4.0	5	14.3
Battery can burst	1	2.7	2	8.0	1	2.9
It may be poisonous	3	8.11	-	-	3	8.6
Other, specify	2	5.41	-	-	-	-
Total	**37**	**100**	**25**	**100**	**35**	**100**

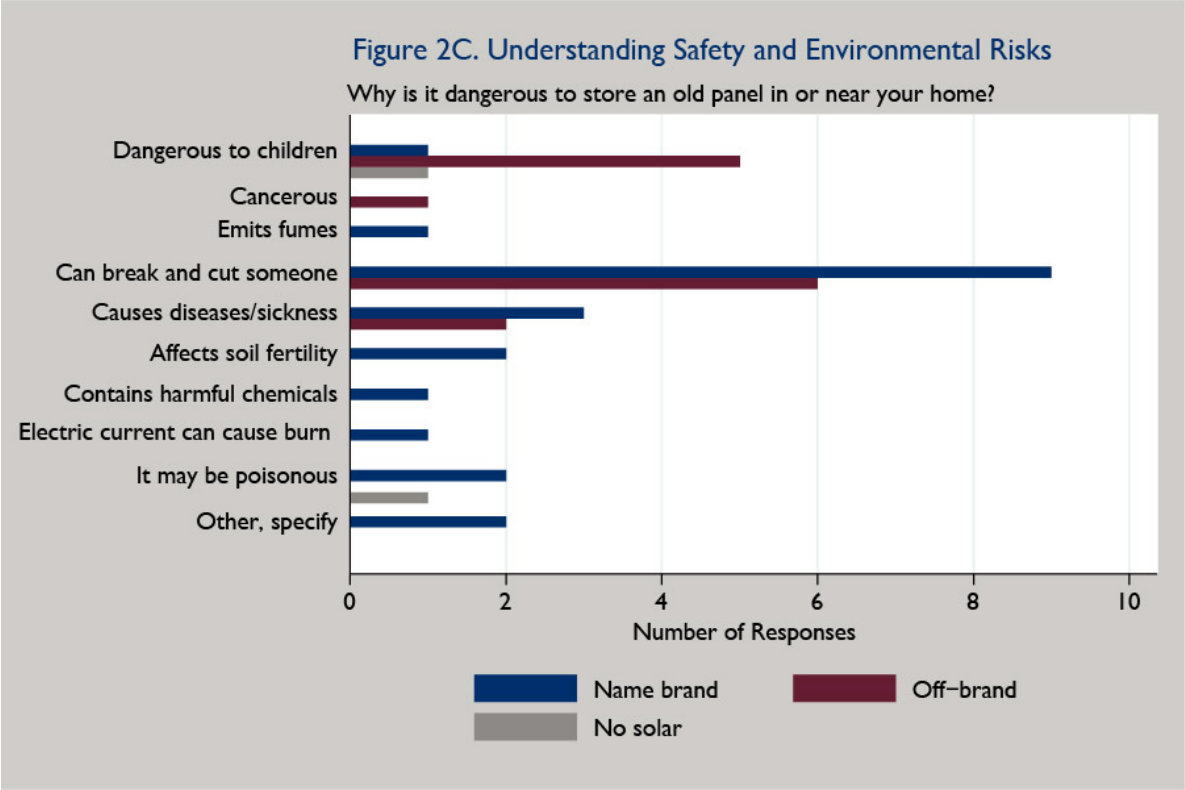


B. BATTERY

WHY IS IT DANGEROUS?	OWNERS OF NAME-BRAND SHS		OWNERS OF OFF-BRAND SHS		HOUSEHOLDS WITHOUT SOLAR	
	Freq.	%	Freq.	%	Freq.	%
Acid in the battery is not safe	10	22.2	12	36.4	1	33.3
Dangerous to children	3	6.7	6	18.2	1	33.3
Cancerous	3	6.7	2	6.1	-	-
Emits fumes	5	11.1	1	3.0	-	-
Causes diseases/sickness	3	6.7	6	18.2	-	-
Affects soil fertility	6	13.3	-	-	-	-
Contains harmful chemicals	3	6.7	1	3.0	-	-
Electric current can burn someone	5	11.1	1	3.0	1	33.3
Battery can burst	4	8.9	3	9.1	-	-
It may be poisonous	3	6.7	1	3.0	-	-
Total	**45**	**100**	**33**	**100**	**3**	**100**

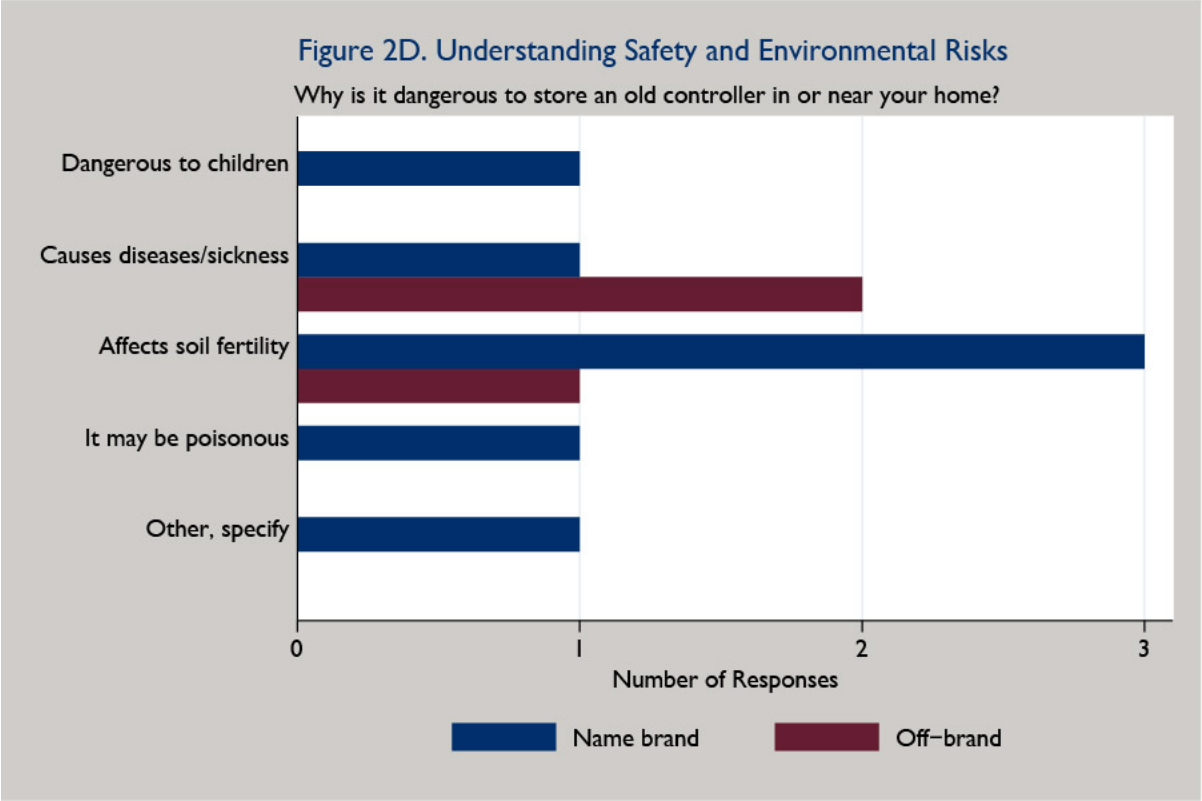
C. PANEL

WHY IS IT DANGEROUS?	OWNERS OF NAME-BRAND SHS		OWNERS OF OFF-BRAND SHS		HOUSEHOLDS WITHOUT SOLAR	
	Freq.	%	Freq.	%	Freq.	%
Dangerous to children	1	4.6	5	35.7	1	50.0
Cancerous	-	-	1	7.1	-	-
Emits fumes	1	4.6	-	-	-	-
Can break and cut someone	9	40.9	6	42.9	-	-
Causes diseases/sickness	3	13.6	2	14.3	-	-
Affects soil fertility	2	9.1	-	-	-	-
Contains harmful chemicals	1	4.6	-	-	-	-
Electric current can burn someone	1	4.6	-	-	-	-
It may be poisonous	2	9.1	-	-	1	50.0
Other, specify	2	9.1	-	-	-	-
Total	**22**	**100**	**14**	**100**	**2**	**100**



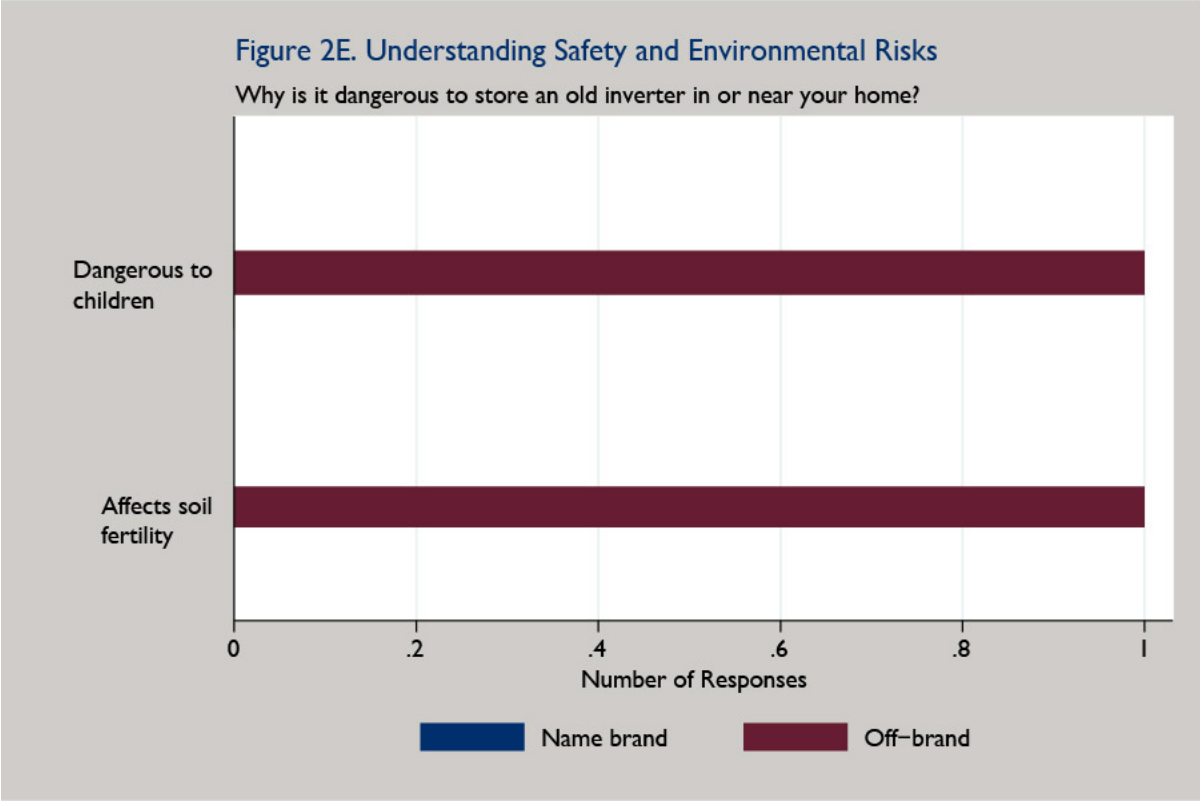
D. CONTROLLER

WHY IS IT DANGEROUS?	OWNERS OF NAME-BRAND SHS		OWNERS OF OFF-BRAND SHS	
	Freq.	Percent	Freq.	Percent
Dangerous to children	1	14.3	-	-
Causes diseases/sickness	1	14.3	2	66.7
Affects soil fertility	3	42.9	1	33.3
It may be poisonous	1	14.3	-	-
Other, specify	1	14.3	-	-
Total	**7**	**100**	**3**	**100**



E. INVERTER

WHY IS IT DANGEROUS?	OWNERS OF NAME-BRAND SHS		OWNERS OF OFF-BRAND SHS	
	Freq.	Percent	Freq.	Percent
Dangerous to children	-	-	1	50
Affects soil fertility	-	-	1	50
Total	**-**	**-**	**2**	**100**



F. SOLAR LANTERN

WHY IS IT DANGEROUS?	OWNERS OF NAME-BRAND SHS		OWNERS OF OFF-BRAND SHS		HOUSEHOLDS WITHOUT SOLAR	
	Freq.	%	Freq.	%	Freq.	%
Can break and cut someone	1	33.3	-	-	3	42.9
Contains harmful chemicals	1	33.3	-	-	1	14.3
Affects soil fertility	-	-	1	100	-	-
Causes diseases/sickness	-	-	-	-	2	28.6
It may be poisonous	-	-	-	-	1	14.3
Other, specify	1	33.3	-	-	-	-
Total	**3**	**100**	**1**	**100**	**7**	**100**

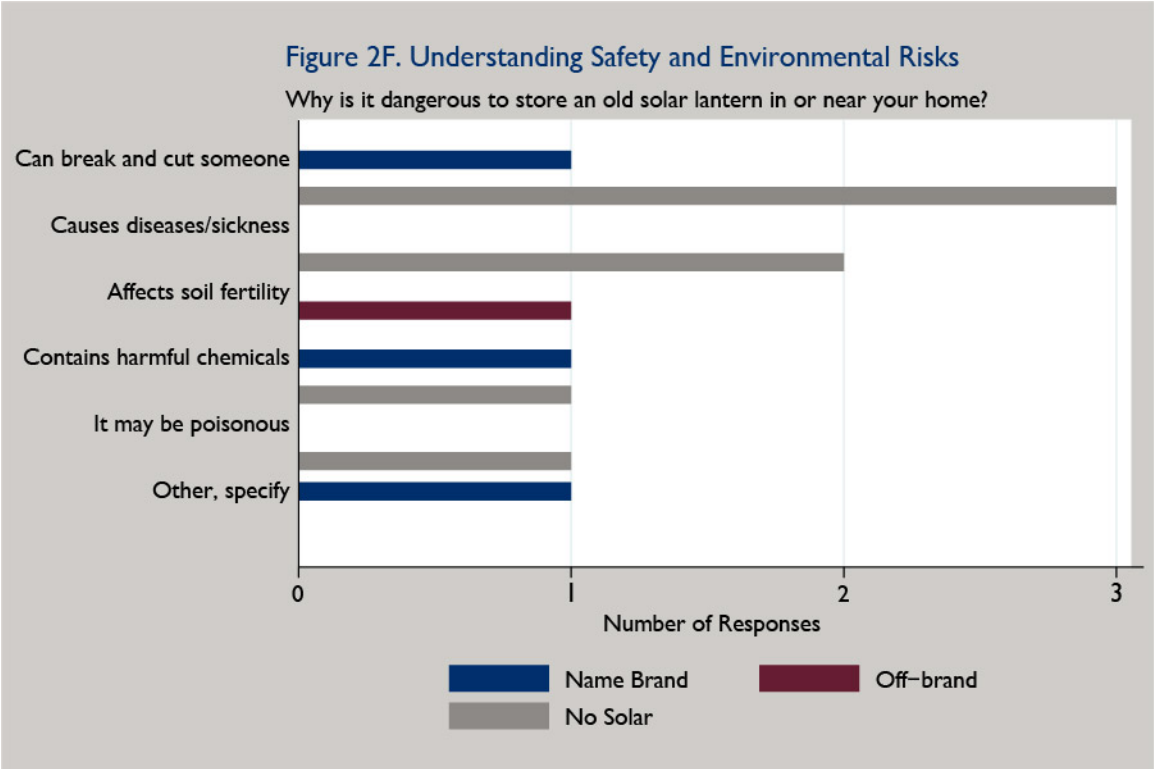


Figure 2F. Understanding Safety and Environmental Risks
Why is it dangerous to store an old solar lantern in or near your home?
Can break and cut someone
Causes diseases/sickness
Affects soil fertility
Contains harmful chemicals
It may be poisonous
Other, specify
0
1
2
3
Number of Responses
Name Brand
Off-brand
No Solar

RESEARCH NOTES: CONSUMER HOUSEHOLD SURVEY DATA COLLECTION PROCEDURES

Data Collection and Management

The data collection and survey process was overseen by RAN and IPA. Survey answers were recorded in person by experienced field officers on a tablet at the time of the interview and answers selected or transcribed by the research assistants. Responses were coded using Survey CTO using a pre-set coding structure.

Confidentiality

Data from all participants were stored in the RAN and IPA offices in Kampala, secured by a password protected system. All personally identifiable information was removed from the responses and stored separately. All data used in this report is summarized and does not reflect any individual household or region.

Data Analysis

Analysis of all survey response data was performed in STATA 14, with original data stored separately to preserve accuracy. Evaluation of household value was done using data pulled from the World Bank Living Standards Measurement Study for Uganda, 2015-2016. A linear probability model was used in the regression analysis.

Ethical Considerations

Approval to carry out this study was sought from Makerere University, College of Humanities, School of Social Sciences Higher Degrees Research and Ethics Committee and the Uganda National Council of Science and Technology (UNCST). Permission to conduct the interviews was sought from the respective institutions and stakeholders. Voluntary informed consent was obtained from all study respondents. All information obtained during the study is treated as confidential and anonymized data will be shared with relevant stakeholders and as per the USAID data sharing requirements. All identifier variables will be removed from the data before sharing it with the stakeholders following the USAID data sharing policy.