THE GLOBAL LEAP SOLAR E-WASTE CHALLENGE

MARKET SCOPING REPORT

OCTOBER 2019
GLOBAL LEAP AWARDS

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Abbreviations and Acronyms

CSR	Corporate Social Resposibility
DFID	(U.K.) Department for International Development
EoL	End-of-Life
EMPA	Eidgenössische Materialprüfungs und Forschungsanstalt Swiss Federal Laboratories for Materials Science and Technology
EPR	Extended Producer Responsibility
GOGLA	Formerly Global Off-Grid Lighting Association
IFC	International Finance Corporation
IP	Intellectual Property
LCA	Life-Cycle Assessment
GIZ	Deutsche Gesellschaft fur Internationale Zusammenarbeit GmbH
LED	Light-Emmitting Diode
LGQA	Lighting Global Assurance
LiFePO4	Lithium Fero-Phosphate
Li-Ion	Lithium Ion
NEMA	National Environment Management Authority (Kenya)
PAYG	Pay-As-You-Go
PCB	Printed Circuit Board
PSP	Pico-Solar Product
RAN	ResilientAfrica Network
SHS	Solar Home System
SOGE	Scaling Off-Grid Energy
SSA	Sub-Saharan Africa
StEP	Solving the E-waste Problem
SRI	Sustainable Recycling Industries
TEA	Transforming Energy Access
UC Berkeley	University of California- Berkeley
USAID	United States Agency for International Development
UNU	United Nations University
WEEE	Waste Electrical and Electronic Equipment
Watts (W)	Unit of power

List of Figures and Tables

Timeline

The evolution of off-grid solar
e-waste management efforts

2013

GOGLA and International Finance Corporation (IFC) e-waste workshop in Munich

2014

GOGLA Industry Opinion on Recycling released

Nairobi Recycling Working Group round-table held in Nairobi

SolarAid co-fund first research project on end-of-life

First report on solar e-waste released by Total

2015

Solar e-waste conference at Strathmore University in Kenya

Sustainability session at 4th International Off-Grid Lighting Conference and Exhibition, Dubai

Global Off-Grid Solar Scorecard launched

2018

Sustainability session at the Global Off-Grid Solar Forum and Expo in Hong Kong

CDC E-Waste Workshop at M-Kopa campus in Kenya

Solar E-waste Workshop hosted at Strathmore University in Kenya

2019

Launch of Global LEAP Awards Solar E-Waste Challenge

Launch of GOGLA E-waste Toolkit

GOGLA E-Waste Festival hosted in Nairobi

Introduction

1.0 Overview

Sustainable management of solar e-waste is an emerging priority for the off-grid solar sector. Solar e-waste refers to pico-solar products (PSPs), solar home systems (SHSs), and solar-powered appliances at their end-of-life. A recent study estimates that 26.2 million solar lanterns and SHSs have already reached their end-of-life in sub-Saharan Africa and South Asia (GOGLA 2018). In Kenya alone, 3-4% of the 55,000 tons of total e-waste produced in 2017 was from PSPs and SHSs. Recapture and recycling of off-grid solar e-waste is particularly challenging for three reasons:

- **Collection Cost:** There is a high cost to collect products from remote areas for two reasons: logistics and incentives. The logistical cost of reaching dispersed users' homes and returning waste products to a centralized location is high because of distance and terrain. There is an incentive cost because when asking for waste, the holder of the waste product assumes there is value in the product's materials and so will want compensation to give up their product.
- **Battery Diversity:** SHSs use a variety of battery chemistries. Lithium-based batteries dominate in pico-solar products and are increasingly found in smaller SHSs (<50W), but there is currently no lithium battery recycling facility in Africa. Instead, they are sent to Europe for recycling. While larger SHSs have lead-acid batteries, for which local recycling options exist and there is a positive recycling value, not all local facilities meet environmental, health, and safety standards. Improper disposal of lead acid batteries can lead to the contamination of food and water sources.
- **Multiplier Effects:** The weight of SHSs and the presence of more copper cabling increases their positive recycling value compared to PSPs. However, the typical distribution model of bundling SHSs with other end-use appliances increases overall waste volumes, therefore increasing collection costs. The multiplier effect is especially challenging when SHS and appliances are "locked" together by proprietary software or hardware and cannot be used independently. If just one part of a system fails, its still-functional accessories and appliances may become waste too.

E-waste management has long been on the agenda in the off-grid solar sector. The Global Off-Grid Lighting Association (GOGLA) published an Industry Opinion on the topic as early as 2014 recognizing the importance of e-waste in the industry's long-term sustainability goals. Some of the leading off-grid companies, including Greenlight Planet, M-KOPA, Mobisol, and ZOLA Electric, have taken action to manage their waste by establishing partnerships with emerging recycling companies such as the WEEE Centre in Kenya and Phenix Recycling[1] in Tanzania.

1.1 Global LEAP Solar E-Waste Challenge

Despite action on behalf of some key actors, e-waste management efforts in sub-Saharan Africa remain nascent. In an effort to catalyse partnerships and support innovation for off-grid e-waste management, in March 2019 the Global LEAP Awards[2] launched the **2019 Global LEAP Solar E-Waste Challenge.** The **Solar E-Waste Challenge** made $1.6 million available in grant funding to support innovations in e-waste management in the off-grid sector in sub-Saharan Africa.

The Challenge is an initiative of the Efficiency for Access Coalition, implemented by CLASP, and supported by the U.S. Agency for International Development (USAID) and UK Aid as part of the Scaling Off-Grid Energy (SOGE) Challenge for Development and Transforming Energy Access (TEA) programs. As the co-Secretariat of the Efficiency for Access Coalition, CLASP develops and implements appliance energy efficiency programs, including the Global LEAP Awards, that play a critical role in accelerating access and meeting the growing demand for energy services in on-, off-, and weak-grid markets.

1 Phenix Recycling has since ceased all operations.
2 The Global LEAP Awards is an international competition to identify and promote the world's best off-grid appliances, accelerating market development and innovation.

Grants ranging up to $200,000 were available for the following:

1. Solar home system distributors seeking to pilot and implement end-of-life programs
2. Recycling and e-waste management companies seeking to expand business activities in support of the off-grid sector across sub-Saharan Africa
3. Other specialized service providers with operations that are directly relevant to responsible solar e-waste management

The 2019 Challenge received 159 applications to implement projects in 49 countries across the continent (Figure 1). The greatest number of applications came from East Africa, where the market for off-grid solar energy is the most robust and developed. The eight winners represent four recycling and four solar distribution companies that will implement projects over a 12-month period in Kenya, Uganda, Rwanda, Zambia and Nigeria.

The aim of the Challenge is to encourage greater investment in the long-term sustainable growth of the off-grid sector. The next iteration of the Solar E-Waste Challenge launched in October 2019 with a focus on battery technologies and product design.

The Solar E-Waste Market Scoping Report outlines the current state of knowledge and activities on solar e-waste management in sub-Saharan Africa. The report informed the design of Global LEAP Awards Solar E-waste Challenge, particularly the categories of prizes and application evaluation criteria. It will also act as a baseline for later program impact assessments.

Solar E-Waste Challenge Nominees

Figure 1. Highlighted countries represent locations for Global LEAP Solar E-Waste Challenge nominated projects.

1.2 Scope of Report

The report complements research conducted by the ResilientAfrica Network (RAN) research group at Makerere University (Kampala, Uganda) and a research group at the Haas Energy Institute at University of California, Berkeley (UC-Berkeley, USA). The RAN research report provides a qualitative overview of the off-grid solar sector in Uganda and Senegal. UC-Berkeley examined user attitudes toward and awareness of the effects of household disposal practices on human and environmental health. This Global LEAP Awards report examines all off-grid solar products (from solar lamps through pico-lanterns to solar home systems) and associated appliances covering all of Sub-Saharan Africa. The report examines e-waste from both -verified and non--verified solar products, recognising that non--verified products represent a majority market share and, therefore a greater volume of solar e-waste generated at the end-of-life (EoL). The report also recognises that some solar e-waste comes from products that are never sold or used, including prototypes, display products, and unsold stock when new product lines are introduced.

The report focuses on two key components of the solar e-waste system:

1) Business design for product servicing and repair as well as product collection or 'take-back'
2) E-waste recycling infrastructure

The report identifies several barriers the Solar E-Waste Challenge is seeking to address, including

- **Costs.** The costs involved in the responsible management of solar e-waste. The primary costs associated with e-waste management come from securing waste from consumers, transporting it to a central location, storing it and then processing (where such facilities exist).
- **Current data gaps.** Data gaps on the specific quantity, location and material make-up of solar e-waste create a major challenge for downstream recycling partners. This is particularly true in non-vertically-integrated business models. There is also a lack of knowledge among solar companies around the location of recycling facilities, particular processes and their associated costs.
- **and trust.** Ensuring the of product performance in repair processes and maintaining the trust of consumers, waste partners and industry peers in collaborations are further challenges when implementing effective solar e-waste management.

Pay-as-you-go (PAYGO) business models have the potential to improve solar e-waste management systems. The model offers opportunities to create greater consumer awareness around proper product usage and disposal through company communications. Furthermore, PAYGO can offer preventive maintenance services and channels for customers to return waste products to the distributor in order to recycle or dispose of them appropriately.

1.3 Scope of Research

The report is based on a literature review led by independent consultant Dr. Declan Murray, and 17 stakeholder interviews conducted by Declan Murray and Ruth Kimani (CLASP) in January 2019 (see Appendix A for interview questions). Drew Corbyn of GOGLA facilitated company introductions and provided feedback on draft versions of the report.

The majority of interviewees were directly involved in e-waste management, including (reverse) logistics, sustainability or product improvement. The interviews served to garner opinions and experiences in solar e-waste management, with particular emphasis on the challenges and opportunities practitioners face. In some cases, more than one employee or representative were interviewed at the same time. The interview questions are located in both Appendix A and B of the report.

1.4 Report Structure

The report is structured into three sections:

1. Current and historic approaches to solar e-waste management
2. Barriers to reducing volumes and improving the management of solar e-waste
3. Opportunities for improving solar e-waste management

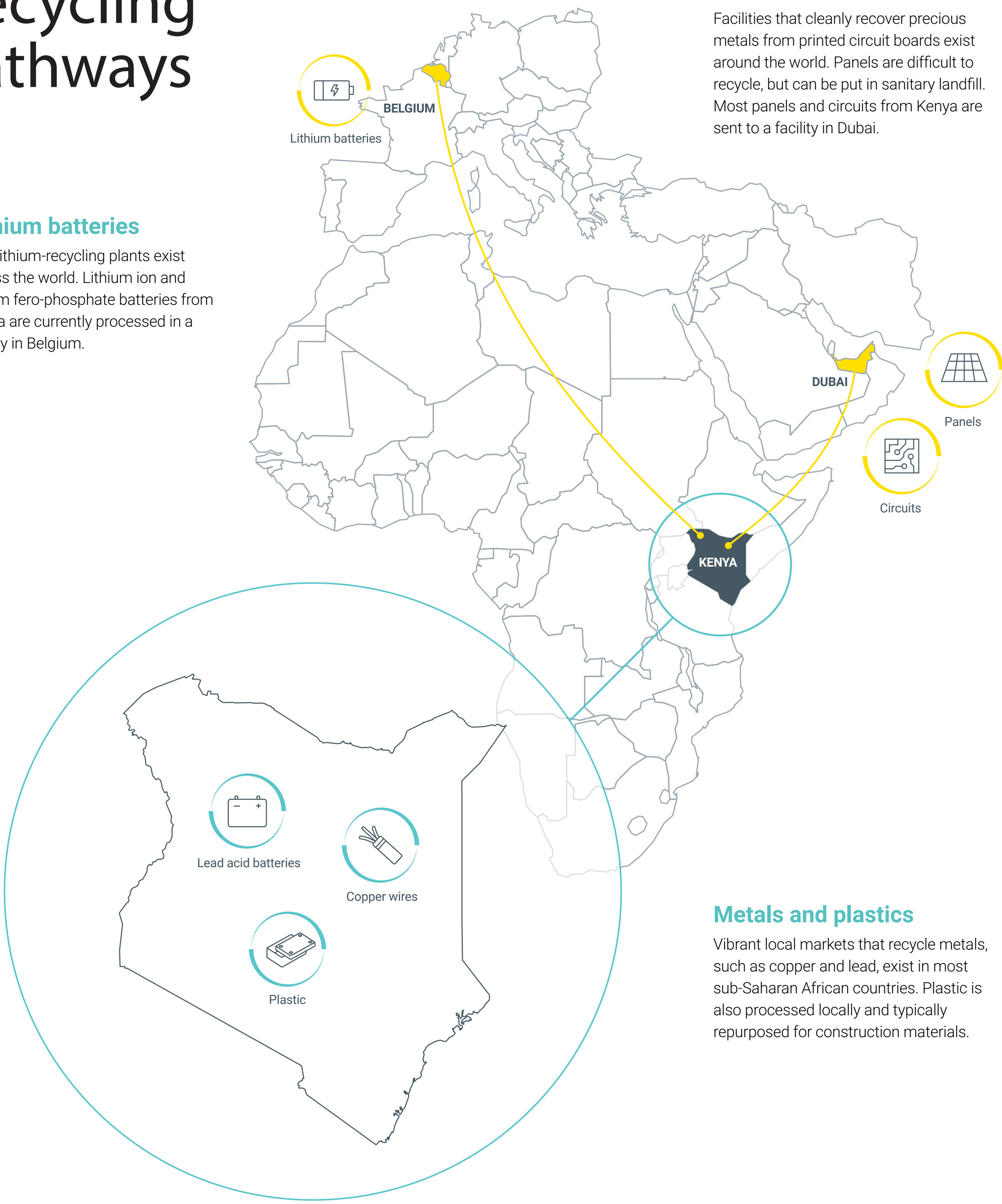
E-Waste Recycling Pathways

Lithium batteries

Few lithium-recycling plants exist across the world. Lithium ion and lithium fero-phosphate batteries from Kenya are currently processed in a facility in Belgium.

Panels and circuit boards

Facilities that cleanly recover precious metals from printed circuit boards exist around the world. Panels are difficult to recycle, but can be put in sanitary landfill. Most panels and circuits from Kenya are sent to a facility in Dubai.



Metals and plastics

Vibrant local markets that recycle metals, such as copper and lead, exist in most sub-Saharan African countries. Plastic is also processed locally and typically repurposed for construction materials.

Figure 2. E-waste recycling pathways originating in Kenya.

Approaches to Solar E-Waste Management

Each of these three sections includes an exemplar case study of good practice.

2.0 Maintenance, repair and collection

Distribution

Over the last ten years, the off-grid solar industry has boomed (Dalberg Advisors and Lighting Global, 2018). New companies are quickly emerging with innovative technologies and business models, including lease-to-own and PAYGO or pay-by-instalment. These companies distribute products through retail outlets, savings and credit cooperatives, partnerships with non-government organizations, and as part of corporate social responsibility (CSR) schemes.

In addition to diverse business models and product types, there is also an accepted division between "certified" and "non-certified" products based on the Lighting Global verification program. Product certification through Lighting Global requires a minimum two year warranty and truth-in-advertising. More recently, affiliation to the GOGLA membership has become another form of product and company certification characterizing the market (Dalberg Advisors and Lighting Global, 2018).

Maintenance, servicing and repair

In order to gain Lighting Global certification, companies must offer a warranty (Lighting Global, 2017) and GOGLA members are publicly committed to making spare parts available (GOGLA, 2014). However, in practice, maintenance and after-sales services can be limited.

Most solar companies interviewed replace, rather than repair, faulty products (Murray, forthcoming). Where company-sponsored maintenance, servicing and repair occurs, interviewees say this happens in large urban centres or capital cities such as Arusha, Kampala, and Nairobi. There are exceptions, such as Solibrium in western Kenya and Village Energy in Uganda; both companies have agents who travel to customers' homes to perform maintenance when necessary.

One commonality is the variability with which companies describe their processes (Murray, forthcoming). Interviewees stated that their companies respond to products on a case-by-case basis. Depending upon the type of problem, the servicing centre, or the employee handling the issue, the servicing process can vary significantly. The majority of companies focus on growing distribution, so their channels for warranty and EoL are subject to change in the future.

Solar companies must balance priorities to increase initial sales and improve after-sales services. One newer company in western Kenya said that while they do "not yet have components that are in obsolete condition," they were confident that "once the need comes…we would be able to take care of that." Companies exhibiting confidence and offsetting the issue of solar e-waste management as a future concern is noted in previous research (Murray, forthcoming).

Outside of company processes, there is a vibrant repair economy in sub-Saharan Africa that predominantly serves rural areas. Solar users take their electronics to a robust network of independent shops for repair (Jackson et al, 2012; Houston, 2013). This network is the sole recourse for non-certified products or those distributed through general electronics retailers – i.e. the majority of products in sub-Saharan Africa today.

Collection and take-back

Although some companies take back products through warranty schemes, take-back purely for disposal or recycling purposes (i.e. out-of- or after-warranty) is less common than repair or maintenance services (GOGLA and Lighting Global, 2015). In the majority of cases, users dispose of waste products themselves at home. Take-back for recycling has received more attention in industry-wide efforts to address EoL than steps to improve product designs that would foster greater reparability or recyclability (GOGLA, 2013; GOGLA, 2014; Cross and Murray, 2018). Furthermore, 63% of solar companies interviewed mentioned previous or ongoing partnerships with recycling companies that manage their waste, particularly in eastern Africa (see also Murray and Corbyn, 2018).

Case Study 1: Solar Distributor

Awango by Total

In 2011, Total introduced its Awango Access to Energy programme to address energy access for low-income communities. To date, Total has sold over one million solar lanterns in 40 countries through their extensive network of filling stations.

Collection and Recycling in Practice

Total offers a warranty on all products. can bring a faulty product to a station and staff will make an assessment to validate the claim. In the seven countries where Total has recycling partners and facilities exist, products are sent for proper recycling. In many countries, recycling facilities do not exist and keeping products in clean storage is the best that can be done.

Since 2015, Total has recycled 50,000 in-warranty products and currently has 41,000 in clean storage awaiting safe disposal. The Total filling station chain also provides a possible network for the collection of products at end-of-life, out-of- or beyond-warranty. Total even collects those sold or distributed by other companies, including non-verified products. Total has consistently expressed interest in collaborating with other producers to leverage this chain, though this has not yet materialized.

Total's E-waste Projects

- In 2015, Total developed a recycling strategy (in partnership with GIZ), focusing on four main topics: awareness, collection, reputable recyclers, and ensuring the financial sustainability of solar lamps recycling.
- In 2018, Total commissioned a lifecycle assessment (LCA) of their solar lanterns to identify opportunities for improvement in design, lifecycle length, and sourcing.
- They have partnered with Aceleron on a project to explore battery collection and reuse in Kenya.
- In 2017, Total entered discussions with Lagazel regarding the possibility of in-country product assembly as a precursor to and facilitator of later repair processes.
- Total is currently supporting an e-waste management company in Cameroon to build a network of informal collectors and establish dismantling and storage facilities. This will target all types of e-waste, not only off-grid solar.

2.1 Recycling

Volumes

In 2016, an estimated 26.2 million pico products were sold globally (Dalberg Advisors and Lighting Global, 2018). Evidence shows that the eastern region is one of the biggest markets for the off-grid solar products in Africa. Around 60% of sales in 2014-2016 were in Kenya alone (Dalberg Advisors and Lighting Global, 2018).

Depending on component , product lifespan is estimated to be 3 years for PSPs and up to 5 years for SHSs (Magalini et al, 2016). The same report paired average lifespan with sales figures to conclude that in 2017, the off-grid solar sector would produce 3,600 metric tonnes of e-waste across 14 countries in sub-Saharan Africa. This number is estimated to rise to 10,000 metric tonnes by 2020 (Magalini et al, 2016). Some research, however, challenges the accuracy of these estimates (Cross and Murray, 2018). Forecasting volumes of solar e-waste is further complicated by the after-sales delay in waste appearance. Similarly, there is a lack of data on sales volumes of non--verified products. Therefore, estimates are even less reliable when considering that the majority of products in use in sub-Saharan Africa are non--verified. There is a critical knowledge gap on estimates and understandings of product lifespans in practice.

Parts and materials

E-waste recyclers consider constituent materials within solar products to be the most important components. Off-grid solar products typically consist of a photovoltaic (PV) module, a battery, LEDs, a plastic casing, copper wires, and a circuit board. When solar e-waste enters recycling chains, the plastics are processed locally (in sub-Saharan African countries). In local facilities, plastics are generally shredded, melted down, and recycled into new items, such as composite fence posts (Magalini et al, 2016).

Lead acid batteries can also be processed locally, although some are sent to companies abroad, such as Nile Limited in India. Other battery chemistries ($LiFePO_4$ and Li-Ion) are exclusively sent to facilities abroad, such as Umicore in Belgium (Figure 2). PV panels are largely stockpiled or disposed of in landfills. LEDs are not currently processed separately from the rest of the non-hazardous components. Although GOGLA members are committed to using standardised components and materials that would facilitate recycling (GOGLA, 2014), products on the market currently use various types of materials that complicate the recycling processes where only single material types can be processed together.

2.2 Locations, facilities, and processes

Infrastructure

Currently, there is no public infrastructure for e-waste collection in sub-Saharan Africa. Any collection happening is either conducted by solar companies themselves, or by e-waste management companies. There are a limited number of formal e-waste dismantling operations in the region, such as the WEEE Centre in Kenya and Enviroserve in Rwanda. Both companies work with multiple solar clients, though were unable to divulge much detail in interviews due to privacy agreements and Memorandums of Understanding.

Security is a concern for e-waste managers in general, particularly when tasked with the destruction of hard-drives from institutions and organisations. Across the off-grid solar sector, there are emerging concerns about data, consumer protection, intellectual property, and product design. Interviewees also raised concerns about the facilities' operating standards and transparency– it is not always clear where companies and collectors move e-waste products. Trust is an important aspect of commercial relationships concerning solar e-waste.

Specialist companies such as the WEEE Centre and Enviroserve typically serve commercial (Total and Mobisol) or governmental clients. However, the majority of e-waste in sub-Saharan Africa is collected by small-scale door-to-door collectors (Oteng-Ababio, 2012). Informal collectors process or recycle e-waste from scavenged waste found in urban dumpsites (Ibid). Collectors either re-sell products or dismantle them

(Ibid) and the parts from these dismantled products are sold locally or exported (Grant and Oteng-Ababio, 2012). Informal business models typically require a small fee for items, or acquire products for free if scavenged from a dumpsite. These businesses operate in the open air, thereby avoiding the need to rent a premise or pay for a business license.

Although seen as separate entities, there are notable instances of collaboration between the formal with the informal sectors. The work of Green Advocacy Ghana (GAG) and Pure Earth in Ghana represents a unique case. In one stakeholder interview, a representative of GAG explained that their company provided a cable stripper to collectors at the Agblogbloshie dumpsite in Accra. The device reduced the need to burn off plastic casings, thereby enabling collectors to produce cleaner copper and improve local air .

The solar product components that cannot be sold are either burnt or left in dumpsites. Users who cannot offload their e-waste with specialist companies or small-scale entities, will dispose of it locally. Figure 3 outlines the mechanisms through which uncollected waste in rural areas is typically treated: buried, burned, or thrown into toilets or bushes (Murray, 2016).

Legislation

E-waste management activity occurs under a variety of regulatory systems across sub-Saharan Africa. Ethiopia, Kenya, Rwanda, Tanzania, and Zambia all have draft bills to address e-waste management (Magalini et al, 2016). However, the majority of e-waste bills have remained in the draft stage for several years. In Ghana, Ivory Coast, and Nigeria, e-waste legislation is already in place, although enforced to varying degrees.

Case Study 2: Recycling Center

Enviroserve Rwanda

The founders of Enviroserve have a background in payment processing and have robust connections in the banking sector across SSA. Many of Enviroserve's first customers were banks, such as Kenya Commercial Bank (KCB), for whom they have recycled ATM, branch and office waste. Although Enviroserve also collects from schools, lodges and electronic manufacturers (e.g. Hotpoint) solar e-waste represents more than 50% of their waste by weight, and over half of that comes from one manufacturer: M-KOPA.

Business model

Enviroserve has facilities in Angola, Kenya, Mozambique, Rwanda and Zimbabwe. As a new e-waste processing facility in East Africa, Enviroserve currently varies their model according to clients: some bring the waste to the facility, while others have Enviroserve collect their waste. At their facilities just outside of Nairobi and Kigali, Enviroserve performs initial material processing using equipment such as a 'boards grinder' that produces dust from which rare earth metals can later be extracted. Processing machines facilitate storage and make for more efficient logistics, such as better packing in lorries to reduce transport costs. Pre-processed materials are then shipped to Dubai for full treatment. The $20m facility in Dubai (funded by the Swiss government) is the largest integrated e-waste facility in the world. "You put a fridge in at one end and get all the necessary materials out the other," said Enviroserve's Kenya representative in an interview. However, some fractions from the Dubai facility will still end up in a 'sanitary landfill' as they have yet to find adequate downstream partners to recycle specific parts, most notably solar modules.

Training and employment

Although it is a sizeable global commercial facility, Enviroserve in East Africa operates as more of a social enterprise. They aim to cover labour costs and prefer to invest in training and employment rather than machinery. While machinery is expensive and risks breakdowns, training and employment offer the opportunity to increase skills and reduce poverty in countries like Kenya and Rwanda, as well as helps the environment.

Barriers and Challenges

3.0 Maintenance, repair and collection

Maintenance, servicing and repair

When discussing after-sales services, interviewees repeatedly emphasised the need to differentiate between product types. Product lifespans differ between PSP and SHS; PSPs generally have a shorter lifespan than SHSs. There appeared to be less interest, certainly from an economic perspective, in repair and maintenance for PSPs. In contrast, they emphasized the need to offer after care services to SHS customers.

Companies that manage their own servicing face high cost for spare parts due to low product volumes as well as, in some regions, unfavourable taxation (e.g. EAC). One interviewee also commented on the high cost to train personnel for field product servicing. In Uganda, solar distributor Village Energy began operations as a service business and later shifted to focus on retail due to low repair revenues. The reluctance of the industry as a whole to pursue standardised components (due to IP concerns) and changes in product design lead to more expensive parts and replacement component obsolescence (GOGLA et al, 2018). Solar companies point to financial factors as a central concern when considering maintenance and repair service options.

Distribution

In general, manufacturers pursue one of two distribution channels: a 'vertically-integrated' business model or selling through a third-party distributor. Solar companies operating in vertically-integrated markets find it difficult to track products. Village Energy and Fenix International mentioned that customers only bring in or return parts of products. In these cases, solar panels are separated from control units or accessories. Relying on customers to bring products to company service centres will pose a problem in the future as systems grow in size and capacity. Implementing stringent controls on refurbished units can assist in tracking a product or part back to the customer. However, some interviewees felt the standard for these controls were too high. Having high refurbishment standards result in many functional products going to waste.

Third-party distributors do not receive much support or guidance on e-waste management. The extent of their interaction with manufacturers is most often limited to periodic product sampling and warranty claims. Mobisol, a manufacturer, noted a sense of responsibility for business-to-business (B2B) markets and offers training to distributors on after-sales service provision. However, currently this support only applies to their sales in Nigeria.

Un-branded, poor-, or non-affiliate products have shorter lifespans and therefore produce waste sooner than -verified or affiliate competitors (GOGLA et al, 2018). By moving exclusively through third-party sales channels, manufacturers of non-QV products are not obligated to provide any after-sales services. Instead, these lower products may move to local repair shops which often face a shortage of spare parts, or the parts are simply irreparable or irreplaceable (Murray, 2017).

Collection and take-back

Emphasis across the off-grid solar market on hard-to-reach rural homes presents a unique challenge for waste retrieval. Mobile solar lanterns and PSPs, popular among rural communities, can be particularly difficult to trace. These products are often bought as gifts or transported across borders after sale. Without smart technology built into some SHSs, their locations are not always known to companies. Furthermore, the relationship between the buyer and seller often ends immediately at the point of sale (for cash purchases) or at the end of the warranty period (for PAYGO purchases).

Without an ongoing relationship or customer data, companies may find it difficult to contact customers to collect products at the EoL. Even for SHS companies who are able to know the location of their products, employees interviewed spoke of the difficulty in tracking and guiding particular products or parts through their respective returns and warranty systems. Without robust tracking capabilities, companies are unlikely to accurately forecast waste volumes by weight for downstream recycling partners.

Access to waste is also potentially expensive (Magalini et al, 2016). In many sub-Saharan Africa contexts, interviewees emphasized that product holders expect to receive financial incentives to give up or return their products. This observation was reiterated by nearly all of the stakeholders interviewed. Successful collection and take-back schemes require awareness and incentives for users to turn in their waste rather than dispose of it inappropriately at home (Awango by Total, 2014). Furthermore, the necessary infrastructure to collect and store waste can be costly after staff and transportation expenses. Currently, some companies argue that these costs outweigh the salvage value of collected products. Action has been minimal due to the high cost and risk associated with investing in e-waste management infrastructure (GOGLA et al, 2018).

Despite the above challenges around product collection, multiple companies explained that they are actively collecting products and are struggling to deal with current waste volumes. d.light and Village Energy were particularly despondent at their lack of space to hold products. In Kenya, M-Kopa introduced a 3-day limit policy: uncollected products left for more than 3 days at service centres are returned to the main warehouse in Nairobi to be recycled.

Communal collection centres are one option to alleviate the growing e-waste volume challenge. The sector has already made calls for open, industry-wide collection programmes (see Manhart et al, 2018). However, market leaders have expressed an unwillingness to cooperate due to "commercial sensitivity" of return rates and product defect points (GOGLA et al, 2018). Companies are reluctant for their competitors to know about how often their products fail and which parts of their products fail. As a result, companies are not willing to pool their waste collections, or if they are, then they will require guarantees regarding who and where such information is kept. The challenge is that alternative, single company-based collection schemes, are ineffective and do not produce enough waste for processing or recycling facilities. Additionally, solely collecting particular brand products presents an ethical question on the impact of leaving other e-waste in place.

The e-waste generated from products and parts that are from non-affiliates or out of warranty remains an environmental and human health challenge (GOGLA et al, 2018). Independent repair shops are a possible collection point, however, they may charge a fee or refuse to relinquish the waste (Murray, forthcoming). Independent repair shops also face the same storage challenge as certified solar companies. Overwhelmed with broken and non-functional products, independent repair shops rarely need to purchase stock and regularly have to clear out their shops for lack of space.

3.1 Volumes and Parts

Volumes

The volume of solar waste, an estimated 800 tonnes in 2014 represents less than 0.3% of waste electrical and electronic equipment (WEEE) in sub-Saharan Africa (Magalini et al, 2016). However, such figures are incomplete. First, SHSs are known as 'e-waste multipliers' because they increase access to or are accompanied by other devices and appliances. Estimated volumes do not capture this multiplying effect. There are also issues with waste estimates not accounting for other factors that affect when a product enters the waste stream, if at all (Cross and Murray, 2018).

There is a time lag between the sale of any electronic device and its appearance in waste streams. The time lag is not a simple reflection of average product lifespans. Users may receive a replacement panel or keep a product at home for a period of time before disposing of it. Similarly, products may not enter waste streams as wholes, but in parts with different weights and a different material composition than at the point of sale. In order to support viable waste businesses, such data gaps must be clarified and filled (Schroeder, 2016).

Regardless of the accuracy of estimates and forecasts, the off-grid solar sector must integrate its waste with wider e-waste streams in order to cover the high costs of collection, transport, and storage. Storage in particular presents a challenge for the broader e-waste community — one organisation in Ghana spoke in an interview of urgently needing a buyer for 40 shipping containers full of plastic casings stripped from cables. When storage is full, companies and organisations are unable to take in more waste. In these instances, products are moved to disposal streams instead of environmentally safe recycling chains.

Components

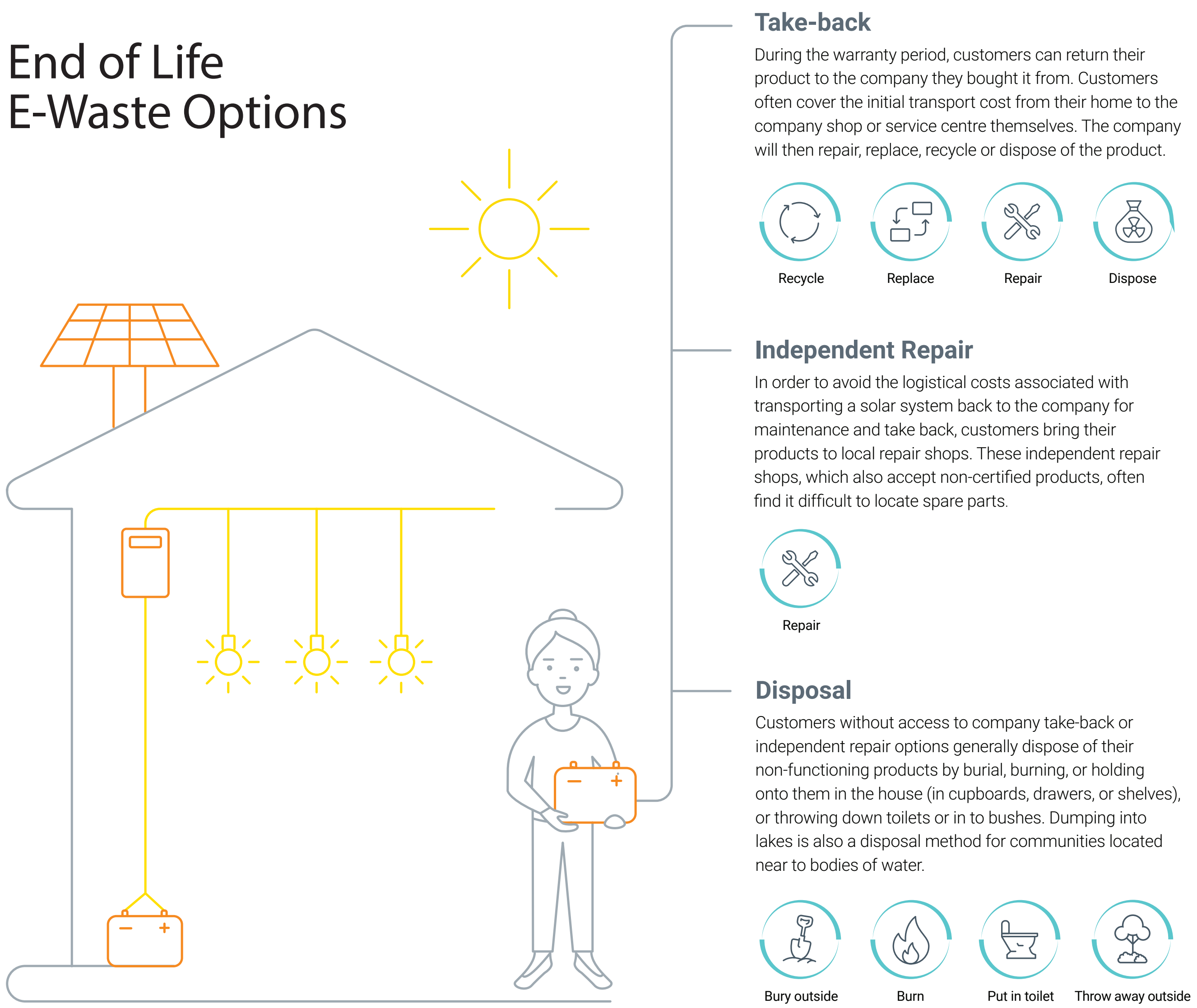


Figure 5. End-of-life disposal options for solar customers in sub-Saharan Africa.

Compared to e-waste in general, solar e-waste presents a unique challenge in terms of diversity of components (Fthenakis, 2000). The compounding of high costs, low volumes, and difficult-to-recycle parts with low revenues necessitate wider attention from the off-grid community to tackle the growing solar e-waste challenge (Magalini et al, 2016). The usage of various battery chemistries, plastic types, and module types make predictions of recycling weights, costs, and revenues challenging. For PV modules, for instance, treatment costs vary from 150-180 €/t for older modules and rise to 220-250 €/t for new modules that use thin film technology (Magalini et al, 2016). The overall negative value for the smaller PSPs is less when moving to SHS with longer cables, larger batteries and associated appliances (GOGLA et al, 2018). The cost of recycling a PSP is greater than the value of the materials recovered at the end, however, SHSs carry a positive recycling value; the cost of recycling a SHS is matched by the value of the materials that are recovered through the recycling process. Ultimately, the sector must accept that current $LiFePO_4$ and Li-Ion products, which dominate the PSP market, represent a net cost (Manhart et al, 2018).

Locations, facilities and processes

There are usually local markets for base metals, like copper and aluminium, and plastics, but panels and batteries must be sent abroad for processing (Magalini et al, 2016). Moving products abroad diminishes the local benefits of e-waste management, such as job creation and industrial development. Although local metal and plastic processing is preferable to save on carbon emissions, it is not always the safest option (Manhart et al, 2018). In interviews, Mobisol and ZOLA in Tanzania said they struggled to find reliable recycling partners in country.

The lack of reliable facilities and markets to sell e-waste products presents a growing challenge (Magalini et al, 2016). One off-grid investor was so concerned about the issue that they considered investing in WEEE Centre (a recycling facility in Nairobi) to upgrade processes there. However, there were noted concerns regarding the Centre's operations, particularly regarding data protection. Since winning the Global LEAP Awards Solar E-Waste Challenge, WEEE Centre has funding to further develop data protection policies. A different e-waste management company, which specialises in the off-grid sector, spoke in an interview of solar companies returning to them after being "burned" (mistreated) elsewhere. Companies that had worked with less reputable waste providers found their waste moved to a landfill, a practice that went against company policy and investor expectations.

Many companies initially opt for a less expensive partner because processing rates can be substantial. It is crucial for companies to understand the reasons behind cheaper waste management options; oftentimes, costs are lower because the processing is environmentally unsafe. Companies should be aware of the value in paying higher prices for safer disposal options.

Solar companies cannot expect, as their customers do, to be reimbursed or compensated for relinquishing their waste. One investor stressed the need for further awareness among solar companies on the processes and associated costs of managing e-waste products. In one example, solar companies smashed their panels before giving them to recyclers out of fear of data leakage. However, by doing so, they drastically reduced the panels' market value. The off-grid solar community is in need of innovative solutions to make e-waste operations economically viable.

The Informal Sector

Whether formal or informal, there is an urban bias in sub-Saharan African e-waste processing. Comparatively, little e-waste moves from rural areas to urban centres. In interviews, e-waste initiatives in Kenya predominantly spoke of partnerships with institutions and companies rather than individuals or residential areas – areas typically served by the informal sector.

Issues arise in the distribution of waste between the formal and informal sectors. Representatives from formal facilities lamented in interviews that informal collectors take large quantities of particular types of waste, such as plastics and lead acid batteries, thereby diverting the fractions away from their facilities. Formal facilities require large amounts of waste to ensure their operations are economically viable in order to afford expensive processing equipment, personnel and meet health and safety standards. Efficiencies in the informal sector can undermine formal sector operations.

Legislation

The lack of consistent e-waste management laws presents ongoing challenges for the industry. Where e-waste management policies exist in the region, there is minimal coordination between institutions; different departments and ministries may manage various components of energy policy, waste management, legislation, and enforcement (Magalini et al, 2016). While regulations may encourage or reassure potential e-waste investors, there is a critical need for resources to support the legal framework itself. Governments, for example, may need financial support to develop and, crucially, enforce regulation. There are few examples of extended producer responsibility (EPR) – a global norm for e-waste management – in Africa to date. Rwanda is perhaps closest (Karuhanga, 2018), although it is unclear thus far how successful its implementation has been. The Ghanaian government has also recently passed legislation to address e-waste (SRI, 2018), while legislation in Kenya has been pending since 2013 (NEMA, 2013).

Because the majority of solar products on the market are un-branded with untraceable producers, it is difficult to impose EPR. Requiring the visible (affiliate) waste producers to pay for non-affiliate waste could potentially distort the market by further increasing the price of affiliate products versus their non-affiliate counterparts (Magalini et al, 2016). Many interviewees commented on the challenging regulatory environment in sub-Saharan Africa. Some stakeholders said it was easier to ship waste products and materials outside of the continent than between countries within Africa. For example, Mobisol had been regularly moving waste from Tanzania to Kenya for processing, but a change in Tanzanian law restricting waste importation and exportation has made this impossible. Now, the company's waste storage is under even greater pressure.

Openings and Opportunities

4.0 Maintenance, repair and collection

Although after-sales and end-of-life services are currently not a priority for solar companies, there is evidence that the provision of after-sales services increases user trust in the technology (GOGLA and Lighting Global, 2015). There is also an opportunity for the creation of a secondary solar market for refurbished products (GOGLA and Lighting Global, 2015). A secondary solar market could deepen market penetration by extending energy access to the very poorest African markets, many of whom currently remain outside of the industry (Lepicard et al, 2017).

At the company-level, existing digital payment and monitoring platforms could enable preventive maintenance (Murray and Corbyn, 2018) as could moves to "energy as a service" business models (Verhoef, 2016). Smart systems are also generating accurate data on the actual lifespan of products, or the period of time that products are functional. Actual lifespan is a data point that is currently poorly understood by industry actors (GOGLA et al, 2018). Although companies have figures on the lifespan of components and advertise the ideal or intended lifespans of their products, there is anecdotal evidence to suggest that actual lifespans vary considerably among users. There is also a gap between company-intended lifespan and user-experienced lifespan (Cross and Murray, 2018). To date, the industry has been reliant on assumptions of product lifespan, generally estimating lifespans at 1.5x the warranty period (GOGLA, 2016). Solar companies could improve current business activities and product designs by collecting regular data on customers' product usage, desires, and understanding of products. Additionally, companies can utilise repair services to conduct consumer education on proper product usage and care (GOGLA and Lighting Global, 2015).

There is also an opportunity for new businesses that specialize in spare parts to support the excessive work streams of local repair shops (Murray, 2017). Support for third-party repair — or independent repair — shops would offer income generating opportunities to "bottom of the pyramid" entrepreneurs (Turing, 2015; Magalini et al, 2016). Many companies are partnering to outsource repairs. One interviewee described a hybrid repairs model where control units of SHSs (high-value, data sensitive components) are repaired in-house, but accessories (low-value, less sensitive) are serviced by a trusted third party. This model allows solar manufacturers to use their repair partner in peak times when their central team is overcapacity. However, one company stressed the need for strong non-disclosure agreements (NDAs) for such an arrangement to work.

4.1 Collection and take-back

There are also opportunities to engage with independent repair shops, common across sub-Saharan Africa, as collection sites (GOGLA and Lighting Global, 2015). Utilizing the shops as local collection sites would drastically reduce access to waste costs. Solibrium, a solar distributor, is partnering with a national informal sector association in Kenya to enhance solar e-waste processing systems.

Another strategy to reduce costs associated with access to waste is to capitalise on last mile distribution networks for collection services (Manhart et al, 2018). Total has trialled this in the past (Manhart et al, 2018) and more recently offered to collect and transport waste for various manufacturers and distributors using its network of fuel stations across sub-Saharan Africa (GOGLA et al, 2018). In interviews, various companies expressed similar willingness to collaborate with other solar companies moving forward. Fenix spoke of the sector's responsibility to act on an ethical basis. The representative argued that action on solar e-waste would help protect the reputation of the entire sector and therefore, Fenix's own longevity and profits. For companies still reluctant to collaborate on product collection, investors can emphasize participation in end-of-life as a way to gain competitive advantage over rivals (Murray and Corbyn, 2018). Another strategy is to introduce a date cap on product collection and only process older products to account for concerns about IP and data leakage.

In addition to raising awareness and providing services, PAYGO models offer more stable relationships and opportunities for takeback. Utilizing system geo-location and battery health remote monitoring could inform forecasts of waste volumes. A focus on collection from institutional customers and bulk distribution (i.e. for emergency or CSR programmes) which presents ready and more easily accessible volumes for recycling could further address the volume challenge (Magalini et al, 2016).

There are positive examples fo sector leadership addressing the issue. Solibrium, for instance, is currently running an extensive internal research programme on solar product end-of-life management. Additionally, Total, who has conducted one of the few life cycle assessments (LCAs) on off-grid solar products are also exploring the sustainability of their component sourcing. Paying closer attention to their product supply chains will allow Total to be more involved in managing their EoL chains as well.

4.2 Recycling

Volumes

The continued growth of the off-grid solar industry (Dalberg Advisors and Lighting Global, 2018) is in some ways compatible with a response to the problem of solar e-waste – the more waste there is the more viable a recycling business becomes. In addition, 10 years after the launch of the influential Lighting Africa (now Lighting Global) programme, there are increasing numbers of products that have reached their EoL.

Locations, facilities and processes

Similar to the possibility for new businesses to emerge around the maintenance and repair of solar products, there is a growing need for new innovations that focus on collection and recycling. Companies like Recykla International, BESIC Group, and EWIK in Nairobi are already developing tracking apps and platforms. These technological innovations could help companies and the greater sector locate and access waste. Furthermore, technology can assist solar companies to improve stock management by tracking component weights and volumes. Robust stock data will improve waste forecasts for downstream partners.

The work of BESIC, EWIK, and Recykla is focused on the nexus between the formal and informal recycling sectors. According to one study, recycling activities in Kenya, Rwanda, and Nigeria were largely executed in the informal sector (Magalini et al, 2016). Formalizing the informal sector, or fostering collaborations between the two, could spur employment opportunities and foster innovation. There are also robust opportunities to improve awareness and share best practices in the informal sector in order to improve environmental and human health outcomes. Increasing awareness could be achieved through the provision of relatively cheap and simple machinery, such as a cable stripper. Providing equipment and education on proper usage increases the informal sector's understanding of healthy and safe e-waste management practices. More intentional efforts on the behalf of off-grid solar companies to include the informal sector could improve infrastructure and processing standards of recycling for e-waste more broadly (Manhart et al, 2018).

Although some studies have highlighted SHS companies operating in-house or in-country recycling services (Batteiger, 2015; Cervantes-Barron, 2016; Pepinster, 2012), it is likely that a more collaborative model will be needed. In interviews with Zola, Mobisol, d.light, and Total, all mentioned the need for shared resources on available recycling facilities, expected recycling rates, and particular recycling processes. The GOGLA E-Waste Toolkit aims to address these needs with modules on recycling components, waste reduction strategies, and the financials of solar e-waste (GOGLA, 2019).

In addition to raising awareness among solar companies, interviewees also spoke of the need to build capacity among e-waste recyclers. Experts spoke of the need to support the operational aspects of recycling businesses through training and process improvements. Mobisol, in partnership with International Lead Association, is currently working with Associated Battery Manufacturers (ABM) to increase capacity. Other companies have considered similar investments in the WEEE Centre in Kenya. Athina Kyriakopoulou, a recognised solar waste expert, stressed that United Nations University (UNU), Solving the E-waste Problem (StEP, an initiative of UNU) and EMPA (Swiss Federal Laboratories for Materials Science and Technology) already possess the knowledge of operational procedures for e-waste. However, there must be more interaction between the off-grid solar community and these institutions to leverage this knowledge. She suggested bringing in consultants to audit facilities and processes.

Legislation

The current void of legislation and regulation, although a barrier to action and investment, presents an opportunity for solar market actors to ensure favourable policy decisions (Manhart et al, 2018). Solar market actors, such as national and international trade associations, can offer input to protect their interests and those of the market (Turing, 2015).

Case Study 3: Solar Manufacturer
Mobisol

Mobisol is a vertically-integrated solar home system provider that manufactures, distributes and services large home and commercial solar systems, integrated with proprietary PAYGO software. The majority of their customers are in Kenya, Rwanda and Tanzania.

Company values
Mobisol's commitment to e-waste management is rooted in the values of the company's founders. Starting with the introduction of a high-level e-waste management policy in September 2017, Mobisol adopted a Code of Ethics in February 2018, codifying the company's commitment to resource efficiency and ideas of the circular economy (CE).

Collection and recycling in practice
In 2017, Mobisol began a scoping exercise to identify recyclers in every country where they were operational. In 2018, they announced three new recycling partnerships: Phenix Recycling (Tanzania, subsequently ceased operations), Enviroserve (Rwanda), and Associated Battery Manufacturers (ABM, Kenya).

Challenges and changes
For the lead-acid batteries, in Tanzania Mobisol has been unable to find a recycling partner that complies with their desired health, safety, and environmental standards, despite a number of recyclers being issued a license to operate from the regulator. This challenge is compounded by a law that restricts the transboundary movements of batteries to a neighbouring country that hosts a trusted recycler. In this case, Mobisol stores the batteries safely until a sound recycler can be found in-country, or the batteries can be transported to a recycler elsewhere.

Summary and Recommendations

5.0 Summary

This report indicates a broad commitment among the off-grid solar community to take action to mitigate the risks of solar e-waste. Motivations for solar e-waste management can be summarized into three categories:

1. **Commitment to the future of the off-grid solar industry and its reputation**
2. **Company values and personal ethics of employees**
3. **Investor-driven requests and demands**

There are several examples of sector leadership on the issue of solar e-waste management. For example, Enviroserve generates the majority of their profit from M-KOPA because the company pays a fair price for their solar e-waste to be properly processed. Additionally, representatives from Fenix and Mobisol spoke of a broader obligation on the part of off-grid solar companies to take action on waste. Despite representing just an estimated 0.3% of the total e-waste in the region, the off-grid solar sector is taking a lead on e-waste recycling in sub-Saharan Africa.

Despite a will to act, the sector faces many challenges in realizing the goal of safe and reliable solar e-waste management. In general, solar companies are reluctant to foster collaborative e-waste management relationships. Even in instances of collaborative action, there is reluctance to address non-quality verified, generic brand products. The lack of accurate data on product lifespans and waste volumes complicates efforts to establish recycling partnerships. Other challenges include the costs associated with access to waste, transport and storage.

Action is also stifled by unclear or absent regulations, as well as a lack of reputable recycling infrastructure and facilities in the region. There are also suggestions that the challenges will continue to grow as SHSs increase in size and are accompanied by ever larger appliances and solar panels – making their movement around markets for repair or disposal purposes even more difficult.

5.1 Recommendations

However, this report offers indications of several opportunities where, with adequate grant funding, progress is achievable. Already, investors and solar companies are actively engaging with recycling and waste management facilities. Nascent developments in apps and online platforms could help forecast and track waste volumes, raise awareness among solar users, and connect solar companies to waste partners. Smart PAYG Osystems also facilitate preventive maintenance and product take-back at the EoL. Simple changes to business models could allow for functional products (prototypes, display products and unsold stock) to be used rather than disposed of.

There are robust opportunities for new businesses in the repair sector where, with fewer requirements for regulatory change and lower levels of investment, a large number of solar products could be diverted from waste to lifetime extension. Although material processing machinery is expensive and would require investments beyond the scope of the Global LEAP Solar E-Waste Challenge, in many cases small or less expensive equipment can improve processes. The informal sector in particular could benefit from minor equipment investments that could drastically improve the impact of waste on human and environmental health. Investing in the informal sector pre-processing services both increases payments to waste producers and decreases storage and transport costs for processers.

A key consideration the Challenge must recognize is the importance of distinctions. The differences between PSPs and SHSs, batteries and other components, -verified and non- verified products, vertically-integrated and third-party distribution, and informal and formal sectors are all distinctions that may require targeted interventions.

Further Research

Further research should highlight the challenges and opportunities that exist within the informal sector. Additional insights should focus on diverse products and business models in all countries of sub-Saharan Africa, not only the conscientious community of certified companies and distributors that are clustered in East Africa. This report also neglects the consumer perspective but further research into customer insights can be found in the forthcoming UC-Berkeley study.

Glossary

Extended Producer Responsibility	a practice where companies pay a fee on importing goods into a country based upon their market share in that sector. Those fees are then used to pay for the treatment of the e-waste col lected in that country in that year
fraction	a part of a product or waste stream that has originated in the same product or waste stream but needs to be separated from the other parts in order to be disposed or recycled
vertically-integrated	companies which control the whole process from product design through manufacture, distribution, financing and after-sales servicing, as opposed to other companies which may focus on just one of those stages

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Appendix A: Solar E-Waste Questionnaire

Appendix A: List of interviewees

Number	Date	Organisation	Individual(s)
1	14.01.19	Green Advocacy Ghana	Yaw Osei
2	14.01.19	Recykla International	Eric Guantai
3	15.01.19	M-Kopa	Daniel Stoker, Harini Hewa Derage
4	16.01.19	Village Energy	Giuseppe Gregu
5	16.01.19	Chilambo General Traders	Gideon Chilambo
6	16.01.19	Total	Florent Giorgi, Camille Roy
7	17.01.19	d.light	Charlotte Heffer, Wilson Wambugu
8	18.01.19	Enviroserve	Shaun Mumford
9	18.01.19	Zola Electric	Corey Barnes-Covenant
10	18.01.19	Phenix Recycling	Athina Kyriakopoulou
11	18.01.19	BESIC Group	John Kalungi
12	18.01.19	Fenix International	Andrew Loebus
13	18.01.19	Solibrium	Hardley Malema
14	22.01.19	Mobisol	Peter Kossakowski
15	25.01.19	WEEE Centre	Boniface Mbithi
16	20.02.19	EWAM	Deepali Khetriwal

Appendix B: Interview questions

Solar companies (manufacturers & distributors)

1. Company, location
2. Interviewee name and job title
3. Products and business model
    a. PAYGO, cash, loan, other?
    b. Lifespan(s) of products and parts of products
4. Maintenance and repair
    a. Do you currently provide repair and/or maintenance services to your customers?
        i. If so, how and under what conditions?
    b. What are some of the challenges you face with regards to maintenance and repair?
    c. What opportunities do you see for your company in relation to maintenance and repair?
        i. Could you collaborate across the industry? With other electronic waste producers? Or with the informal sector?
5. Collection and take-back
    a. Do you currently do any collection or take-back of products or parts of products?
        i. If so, how and on what conditions?
    b. What are some of the challenges you face with regards to collection and take-back?
    c. What opportunities do you see for your company in relation to collection and take-back?
        i. Could you collaborate across the industry? With other electronic waste producers? Or with the informal sector?
6. Disposal and recycling
    a. What currently happens to products which are no longer in use (and/or faulty, end of life, old stock, returns, damaged, out-of-warranty, cannibalised)?
        i. Are products disposed of as wholes or as parts?
    b. What are some of the challenges you face with regards to disposal and recycling?
    c. What opportunities do you see for your company in relation to disposal and recycling?
        i. Could you collaborate across the industry? With other electronic waste producers? Or with the informal sector?
7. Grants
    a. Has your company previously been awarded any grants?
        i. Which ones? What were your thoughts on the process? What did you use the grant for?
    b. Would a grant help you do (more) for your solar e-waste?
        i. What would you do with it? How much funding/time would you require to implement that project or activity?

E-waste companies (collectors, dismantlers, processors)

1. Company name and location
2. Interviewee name and job title
3. Please describe your business model
    a. Collection/receiving procedure
    b. Fees, revenue sources, payments
4. Types and sources of e-waste
    a. What types of e-waste do you receive? From which sectors, sources, regions and geographies?
    b. And what are their relative frequency, volume and value to the business?
    c. Do you currently handle any solar e-waste, or have you done so in the past?
        i. Which parts? From which companies?
5. Dismantling and processing
    a. What roles do your staff/colleagues perform?
    b. Plant/facilities
    c. Processes (dismantling, melting, shredding, cutting etc)
    d. Where do you send materials afterwards?
6. Industry awareness
    a. What local, national and international regulations and legal frameworks do you need to comply with/are you aware of in your work? i.e. Are you certified by the national regulator according to health and safety standards?
    b. Which other companies are you aware of also servicing the solar industry?
    c. Do you collaborate with other e-waste facilities in terms of collection or processing of specific fractions?
7. Future of the industry/market
    a. What are your company's plans for the future?
    b. What does the future of the industry at large look like in this region/area?
    c. What challenges do you face in this business? i.e. access to waste, confidentiality of clients locating or guaranteeing onward markets for fractions, facilities for processing and storage, infrastructure for collection/logistics
    d. Do you see any opportunities for your business in regards to solar e-waste specifically?
8. Grant funding
    a. Have you applied for grant funding in the past? What did you think of this process? Would grant funding help you overcome the challenges mentioned above? If so, how?
    b. Are you aware of any current grant programmes for e-waste in sub-Saharan Africa?