Innovation & Entrepreneurship Study: Final Report

Spark's Batteries End-of-Life Strategy in Liberia

Company
Spark Energy

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List of Abbreviations

AECF - Africa Enterprise Challenge Fund

B2B - Business-to-Business

CEO - Chief Execution Officer

Co - Cobalt

EoL - End of life

EPR - Extended Producer Responsibility

EU - European Union

EUR - Euro

Fe - Iron

GEF - Global Environment Facility

GOGLA - Global association for the off-grid solar energy

KG - Kilogramm

kWh - kiloWatt hour

LFP - Lithium Iron Phosphate

Li - Lithium

Mn - Manganese

NEP - National Energy Policy

Ni - Nickel

NREAP - Liberia National Renewable Energy Action Plan

OGS - Off-grid solar

PESTEL - Political, Economic, Social, Technological, Environmental, Legal

SDG - Sustainable Development Goal

SHS - Solar Home Systems

SoH - State of health

UNFCCC - United Nations Framework Convention on Climate Change

WEEE - Waste from Electrical and Electronic Equipment

1. Introduction

Electrification is a crucial component in improving opportunities for off-grid African communities. Spark, a Dutch energy firm, currently tackles this by selling solar home systems to rural areas in Sub-Saharan Africa. Thereby, assisting the local communities in gaining access to renewable energy that is affordable, reliable, and sustainable.
However, the LiFePO4 battery packs used to store the energy in these systems are currently uneconomical to recycle. With a lifespan of five years, the issue of managing electronic waste from solar household systems will become increasingly relevant as the first batteries start becoming obsolete at the end of 2023.
The challenge presented by Spark focuses on rethinking their products' end-of-life management by mapping the value chain and identifying active stakeholders. Producing a new business strategy that would keep reverse logistics costs low, be suitable to large-scale recycling, and not alter the current product design is the desired deliverable.

The proposed solution comprises making Spark a proactive actor in the value chain, pushing for future recycling solutions in Africa, and developing a country-specific end-of-life plan for all its markets. Furthermore, the company should strive to educate their end users on proper product handling, product maintenance, and end-of-life options. This ensures an extended product lifespan and appropriate waste disposal of obsolete products.
As the legal environment changes and legislation relating to electronic waste is expected to increase in Africa, it is proposed that Spark should be compliant with the European Union's legal framework regarding waste and extended producer responsibility. This would prepare the company for the implementation of future legislation and comply with international organisations' funding requirements.
Implementing the proposed solution would make Spark’s value proposition towards their distributors more holistic, by adding an end-of-life strategy to their current offerings, and enhancing the possibility of receiving external funding for both parties.

Spark should already start developing, testing, and optimising their electronic waste management system and infrastructure while the majority of their current products have not reached their end-of-life. This would help them in mitigating and resolving issues before the e-waste accumulates and causes problems in the future.

Acknowledgements

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2. Challenge Identification

Spark's challenge was to rethink the end-of-life management for its products by mapping out the value chain and active stakeholders in the African markets where the company is present. The requirements for an eventual solution were to maintain the current product design, keep reverse logistics costs low, follow adept unit economics and the capability of recycling at scale. To better clarify the challenge our group first introduces the company Spark, then chooses one of their specific markets and a product as research focus.

2.1. Introduction to Spark

Spark aims to address the lack of energy provision in rural Africa via modular solar power systems to emerging markets in off-grid communities. These modular systems allow different solar home systems (SHS) configurations by upgrading and adding appliances although Spark provides ready-made solar kits to facilitate the end-user choice. The starter solar kit contains a solar panel, one battery pack, one set of cables, one radio and four LED lamps. The upgraded solar kits add other electronic appliances, namely, a fan, a torch, a TV or a hair clipper, and the extra needed battery packs (Spark, n.d.-a). An overview of *Spark starter* and *Spark supreme* are included in Appendix I. The modular aspect permits the solar systems to fit the end-user needs, financial capacity and any future developments. Furthermore, Spark uses a pre-paid PayGo system in which the end-user chooses to buy the needed energy tokens according to their possibilities. Also, these payments in instalments occur in the *Spark Portal*, a cloud-based service platform for end-users and distributors, that provides speedy transactions with mobile money and SMS integration as well as monitoring and reporting tools for both parties (Spark, n.d.-b).

Despite the focus on the end-user, Spark business model is business-to-business (B2B), which means that Spark sells their products to various national distributors, who are much more aware of the market context and more successful in selling the products to communities (Spark, n.d.-b). From Spark's product portfolio, the company is responsible for the design and development of the battery packs, the solar panels, the lamps, with the rest of the appliances (TV, fan, torch, hair clipper, radio) outsourced to external manufacturers. Due to the recent incursion of Spark products in the African market, most of the sold products have not reached end-of-life yet. However, in order to fulfil Spark's vision of providing "complete energy ecosystem in off-grid communities" (Spark, n.d.-c), the company must develop a strategy for the end-of-life management of their products and avoid contributing to an increasing problem of electronic waste (e-waste) in Africa.

2.2. Choice of Research Focus

Spark market operations extends to 14 African countries. However, during the first contact with Gopika Shibu, it became apparent that focusing on multiple national markets in Africa would be unfeasible in the course's time span. Therefore, it was decided to focus on a single market of interest. In Figure 1, Spark's current markets are depicted and from the brighter green tone becomes evident that the company's operations are spread in the Sub-Saharan region, with the Democratic Republic of the Congo, Liberia, and Nigeria constituting the three largest markets, each with an approximate 17-21% market share (Shibu, personal communication, September 20, 2022).

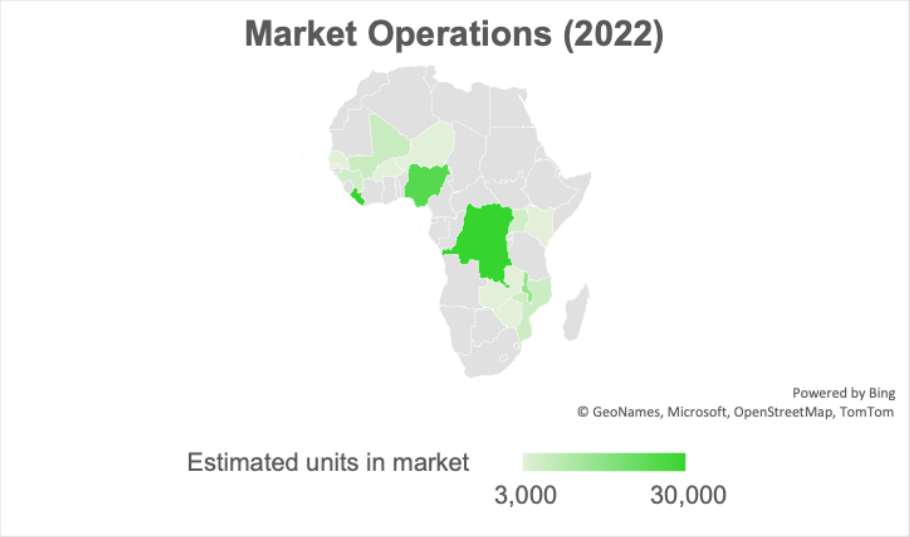

Figure 1 - Spark's current market operations.

From those markets of interest, Liberia was the chosen one due to the over 30.000 solar kits sold in recent years (from 2019) which means that the components with the least life span, such as the batteries, may reach their end-of-life (EoL) soon (by late 2023; Shibu, personal communication, September 20, 2022). For that reason, to develop a Liberian EoL management solution for Spark products would be particularly important. In addition, Liberia lacks any e-waste policy and infrastructure being quite behind compared to other African countries (e.g. Kenya, Rwanda, Ghana; Corbyn, et al., 2019-1) with respect to recycling. Currently, there is only one certified e-waste recycling centre named Green Cities (Lidow, personal communication, 2022, October 11). This void underlines the need for proper EoL management strategy but, also, an opportunity to build a network and system from scratch in Liberia. A PESTEL analysis was carried out, to investigate the macro factors present in this specific market. The complete analysis is available in Appendix II.

○ 2.3. Battery End-of-Life Relevance

From the products under Spark responsibility (battery packs, solar panels and lamps), the battery packs have a lifespan of 2,000 cycles, approximately 5 years, while solar panels can last about 25 years. Therefore, the batteries would be the first element that would stop working from next year.

The battery used by Spark is made of Lithium-Iron Phosphate (LFP; VeraSolar, n.d.). This type of battery is preferred for off-grid SHS systems due to a longer lifespan, low maintenance, high safety within warmer weathers and low energy density (Alexander et al., 2021). However, their complex structure requires a special technique for recycling which can only be done in a few places globally (Corbyn et al., 2019-3). The most known places for recycling are in the United States, China and Europe (Alexander et al., 2021). Due to this problem, it is necessary to have places to store this type of battery. The greatest care that must be taken is with fire since although LFP batteries are those with the least risk of catching fire, they must also be treated with care (stored in barrels with sand).

For Spark, calculating the volume of products that will reach the EoL is an important measure to which the Sales-Lifespan model methodology can be applied, that forecast the EoL volume using the following formula: Waste volume (KG) = Product Sales x weight x lifespan (Corbyn et al., 2019-3).

3. Business Research

This section will explore Spark's current business model in Liberia, by describing their national distributor Lib Solar, the end-users, and the current e-waste management system. Furthermore, this section will also investigate Liberia's current energy market and the consumer profile. In addition, research about Liberia's legal system regarding e-waste is presented. The next part goes into current research on take-back systems and reverse logistics, followed by a section on the hierarchy of battery waste. Lastly, this section concludes the business research by providing a comprehensive system map of the stakeholders and their various relationships.

3.1. Methodology

Semi-structured interviews were conducted to collect primary data about Spark's operations since this method allowed for greater flexibility. There were three interviews conducted with our Spark contact, Gopika Shibu via online meetings at Microsoft Teams. In order to gain more insights about Liberia, we also conducted interviews with Spark's distributor LIB Solar CEO, Nicholai Lidow, and Spark After Sales Lead in the country, Francis Williams. In this case, it was not possible to use the semi-structured method; instead, the interview guide was modified and the questions e-mailed to the interviewee. All interviewees —starting from Gopika Shibu, were sourced through other interviewees who were informed that their responses would be used in this project.
Moreover, the Green Cities CEO, James Mulbah, and the recycling company WEEE centre, in Kenya, were contacted but no reply was received to this date. Hence, academic and grey literature has been used to fill knowledge gaps and gathered from a variety of reliable sources, including relevant organisations websites, journals, and legislation lexicons.

3.2. Spark's Business Model in Liberia

Using the methods outlined in the previous section, the group was able to understand Spark's current operations in Liberia, its partners, resources, and customers. These findings are summarised in the Business Model Canvas that can be found in Appendix III.

3.2.1. Spark's Liberian distributor LIB Solar

Spark operates as a B2B company, delivering its products to a national distributor, that then delivers the goods to the end consumer via local agents. LIB Solar is Spark's distributor in Liberia, which makes them the most important partner in the country due to their logistics and end-user management. LIB Solar describes itself as a data-driven solar company that delivers life-changing products to rural Liberians through a community business model (LIB Solar, 2020). Their headquarters are located in the Liberian capital, Monrovia, and their distributor network spans across all 15 counties of the country (LIB Solar, 2020).
Their business model is focused on capacity building, thus, most of LIB Solar staff is national and the distributors agents are usually from the rural communities to which they provide products to. Therefore, these agents are familiar with the struggles of living in these areas and the end-user's needs which enables a good foundation for communication. Another company's focus is affordability of the products by using the "tech to scale" methodology, which means that rather than selling to individual customers, they aim to mobilise whole communities. More details about LIB Solar's business model are outlined in Appendix IV.

■ 3.2.2. Spark's end users in Liberia

78% of LIB Solar's customers are males and 24% are women. The average age of a customer is 45 years, and the average household size is 7.8. Furthermore, 59% of their customers live in peri-urban areas, 32% in urban areas, and 9% in rural areas.
Concerning community sizes, most of them have between 50 and 100 households, typically serving 25 to 30 of them. 96% of the company's customers use the system for their homes, 3% for a business such as grocery stores or pharmacies, and 2% for both. Their operations are spread across the whole country, but most customers are in Nimba County (35%), which is also the county with the highest population after Monrovia. The county with the second most operations is Sinoe (15%) and then Grand Bassa (14%) (60_decibels, 2022).

■ 3.2.3. Current E-Waste management plan

During an interview with the CEO Nicholai Lidow, the group discovered that LIB Solar made a detailed plan for e-waste management without involving Spark in the process. The main motivation for that was receiving grants from AECF and "Beyond the Grid". It is also expected to have such a plan for a member of GOGLA, which LIB Solar is. The status quo is that batteries and other e-waste are safely stored at the warehouse in an insulated shipping container. Once the waste reaches a critical mass, which is approximately a truckload, the waste will be driven to the local certified recycler Green Cities. Green Cities is located just outside Monrovia and the company will recycle LIB Solar's e-waste and then sell the recycled products to their own customers.
A memorandum of understanding was already signed by both parties. LIB Solar's CEO expects that the first waste will be brought to the recycler by the end of 2023. Furthermore, he predicts that their volume of e-waste will begin ramping up around the third quartile of 2025 and peak in the year 2027. Another challenge LIB Solar will face concerning its e-waste are the inhibitions of end users to give back their end-of-life products. Proud owners of the goods combined with poor education and outreach make collecting the e-waste a difficult task. LIB Solar tackles this problem by offering a free month of subscription to customers who trade in their end-of-life products for a new product (N. Lidow, personal communication, October 11, 2022).

○ 3.3. Liberia Energy Market

Liberia has one the lowest national electrification rates in Africa with ~47% of the urban population and ~8% of the rural population with access to electricity (GOGLA, 2022). The current national generation capacity is about 138MW, mainly from hydropower, and to provide electricity to the capital city of Monrovia (USAID, 2022). Currently, there is no reliable and sufficiently disaggregated data regarding the energy mix of Liberia in terms of energy production and consumption which is a considerable gap to understand properly the national context (GOGLA, 2022; Wesseh & Lin, 2015)
By 2030, the National Energy Policy (NEP) aims to provide energy access to 70% of the population in Monrovia and to 35% of the rest of Liberia's population by extending the electricity grid in the capital and other urbanised areas, and recognising that off-grid energy solutions are crucial for rural areas of the country (GOGLA, 2022; Terneusen, 2018; USAID, 2022). Also, NEP reinforces that cost is the main determinant for energy access, thus, any form of energy project shall be done on a least-cost basis (Wesshe & Lin, 2015). Despite the Liberia National Renewable Energy Action Plan (NREAP) target set to 1.035 million of off-grid energy devices in use by 2030 (GOGLA, 2022), the expectation is that over 50% of the rural population in the country may not have access to electricity by 2040 (Alfaro et al., 2017).

Despite the low public investment in solar energy in Liberia, the country has an enormous solar potential with an average of 325 sunny days per year and, consequently, a significant off-grid solar (OGS) market potential (GOGLA, 2022; Wesseh & Lin, 2015). However, most of the global OGS market is predominantly decentralised, complex and unregulated (Kinally et al., 2022).
This means that a licensed company like Spark, that meets VeraSolar quality certification standards and product sales monitored by GOGLA, has to compete with unregulated potentially cheaper products. Nevertheless, the PayGo system has been widely praised to increase affordability of regulated OGS products, although Spark remains with the challenge of payback periods restricting cash flow and no great financial eligibility information about customers (Kinally et al., 2022).

3.4. Consumer Profile

The common OGS consumer is not connected to the electricity grid (e.g. 96% of LIB Solar customers), with no other electricity alternative (e.g. 69% of LIB Solar customers), and with first-time access to electricity (e.g. 87% of LIB Solar Customers; 60_decibels, 2022). Consumers are rarely well-informed about a correct usage and maintenance of the product as well as the value, risks and correct disposal of e-waste end-of-life (85% of African SHS owners are not aware of its expected lifespan and only 2% are aware of any regional recycling facilities; Rhodes et al., 2020).
There is often an emotional and financial attachment to the products, which means consumers keep non-functioning products at home as something that enriches their lives or as a status symbol, resulting in a product hibernation (Rhodes et al., 2020). Therefore, consumers might have a clear reason to return products while in-warranty, however, there is no incentive to return products that reached EoL because the warranty has expired, another reason to reinforce hibernation.
Nevertheless, owners of name-brand systems typically value non-functioning SHS twice as high as owners of off-brand systems because they are more aware of opportunities to profit from old products (e.g., resale, scrap value, disposal incentives; Rhodes et al., 2020). For that reason, trust brands like Spark are well positioned to inform and influence their customer base to increase take-back by identifying customer barriers (Appendix V) and appropriate incentives. For instance, the 60_decibel report (2022) refers that 98% of LIB Solar customers states that their quality of life improved after acquiring a solar kit due to the ability to charge phones (49%), opportunity for children to study at night (43%), a sense of increased safety (37%), and possibility to spend more time with loved ones (16%). These are already several topics that could be used for targeted communication together with a non-cash incentive take-back system (e.g. discount of new product) to promote a successful behaviour change campaign.

3.5. Liberia End-of-Life Policy & Reality

Liberia does not have any specific legal instruments regarding e-waste management, just general waste management policy and legislation which it is already difficult to implement (e.g. solid municipal waste collection is almost nonexistent; GOGLA, 2022; Schluep et al., 2011).
There is an Environmental Protection Agency that requires an environmental impact assessment of all projects or policies that may have significant impacts on human health and environment and, also, the National Environmental Policy of Liberia that provides a natural resources management and protection of human health and environment framework (Schluep et al., 2011).

Hence, only the global regulatory frameworks of the Basel Convention (1992), on the "Control of Trans boundary Movements of Hazardous Wastes and Their Disposal", and the Bamako Convention (1998), a multilateral agreement between African countries to ban e-waste importation and reinforce the Basel objectives in Africa, are present in Liberia (Maes & Preston-Whyte, 2022; Schluep et al., 2011). However, due to a dualist legal system in Liberia, the international law must be adopted into domestic law which results in a challenge regarding the adoption of specific regulations of these international conventions (Schluep et al., 2011).
Consequently, the lack of appropriate waste management system and policy leads to an informal e-waste sector. This sector covers collection, manual dismantling, re-use of scrap metal, resale of electronic boards, open burning for metal recovery 'urban mining', and uncontrolled dumping of remaining residues on landfills. These activities lead to land, water, air and crop pollution and contamination with human exposure to a range of heavy metals existing in e-waste components (Maes & Preston-Whyte, 2022; Schluep et al., 2011).

○ 3.6. Take-back Systems

A take-back system is a reverse supply chain that reuses, recycles, and composts all materials, resulting in zero waste and a closed loop (Andersen et al., 2022).
The system allows manufacturers to exploit the residual value of products that would otherwise be lost while providing customers with affordable as-new products through repair, remanufacturing, or product life extension design (Bocken et al., 2016). Firms can capture new forms of value by using this sourced lower-cost material with similar properties to the original (e.g., type of material and colour; Bocken et al. 2016). Reuse and remanufacturing retain the residual product value better in such systems, making them preferred over recycling (Linder and Williander, 2017). In Spark's case, it could possibly enable them to create greater local opportunities for the community in which the product functions while lowering the overall environmental footprint of their products.
Logistics is one of the main pillars in the distribution of products in off-grid communities. To do this, off-grid solar companies must consider an intelligent strategy when putting together and putting into practice their logistics. That is why the implementation of reverse logistics should be necessary to meet this objective. An alternative for this modelling could be based on Brito's five dimensions of reverse logistics (Corbyn et al., 2019-5). The model suggests asking *why? who? what? and how?* In the first place, it is necessary for the company to ask itself why it wants to receive the used products, to better understand the forces that drive the company towards a reverse logistics system. This is done to find out the reasons why the product is being returned, the characteristics and type of the returned products. Finally, the company must consider the recovery processes and options, as well as the actors and their roles.

○ 3.7. Battery Waste Hierarchy

To investigate the possibilities of remanufacturing, refurbishing, or recycling the electronic waste it is necessary to understand the definitions. The British Standard BS887-2-2009 (Bakker ét al. 2014) defines the expressions related to extending the use-phase of a product as the following:

- Repair - Returning a faulty or broken product or component back to a usable state
- Remanufacture - Returning a used product to at least its original performance with a warranty that is equivalent to or better than a newly manufactured product

- Refurbishment - Returning a used product to a satisfactory working condition by rebuilding or repairing major components

In Table 1, the hierarchy of design strategies for product life extension and recycling is outlined, and it can be seen that the most effective approach to addressing the waste problem would be to include it during the product design process, to prevent it from entering communities in the first place, or to minimise it as much as possible.

Table 1 - Hierarchy of waste and related design strategies (Bakker et al. 2014; Directive 2008/98/EC)

Hierarchy	Definition (2008/98/EC)	Design Strategy
1. Prevention	Measures taken to reduce the quantity of waste.	Material efficiency Longer product life
2. Reuse	Using a product or component again for the same purpose for which it was conceived.	Product repair Product remanufacturing Product refurbishment
3. Recycling	Any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes.	Product/material recycling

Based on this information the four battery cells used in the main battery module, is LiFePO4 *3.2V IFR26650 3500mAh*, which might be produced by companies such as Sujor Energy (SUJOR, n.d.).

3.7.1. Battery reuse and recycling process

Most research being conducted on the possibility of reusing or refurbishing batteries is for electric vehicles (Lee et al., 2021; Melin, 2019), as they have a much larger capacity than the sizes used in this product, with 40 kWh compared to 0.045 kWh (E.ON, 2022; SUJOR, n.d.; Gomeringer et al., 2017). As a result, the possibilities for refurbishing batteries from the Spark product to store energy elsewhere, would be limited and only usable for products with a lower density requirement. This however, depends on how the battery is considered spent or obsolete. One indicator is the State of health (SoH), it indicates a battery's dynamic status and initial condition. SoH = 100% is the initial (manufacturing) condition. This decreases with time due to irreversible chemical and physical processes called battery ageing. When a battery's ability to store and provide energy falls below a predetermined threshold, it is considered spent, and must be replaced, this point is defined as SoH 0% (Ungurean et al., 2017). Another obstacle is that the product is currently not designed for disassembly and is challenging to dismantle with standard tools (VeraSolar, n.d.).

The material contained in the LFP batteries is available in Appendix VIII, and the following methods are commonly used to recycle them and retrieve it:

Hydrometallurgical extracts metals such as Li, Co, Mn, Ni, and Fe individually from batteries using a suitable solvent such as acid, alkaline, or natural organic acid. Precipitation or electrochemical separation then recovers the metals from the leached solution. (Noor et al. 2022; Peng et al. 2021)

Pyrometallurgy uses high temperatures to decompose used lithium batteries. The operation involves heating used lithium batteries to decompose their components.

In the first step, low temperature prevents electrolyte gas explosions. In the second step, the used battery material is recrystallised at a higher temperature before being roasted and refined (Noor et al., 2022; Wang and Wu, 2017).

It is estimated that the average ecological benefit of recycling spent LFP battery recycling amounts to 330 EUR ton-1 (Noor et al. 2022). Recent research has examined the possibility of recycling these batteries using fewer steps and chemicals at room temperature, and one succeeded in increasing the expected economic profit from 0.28 to 0.84 EUR kg-1 (Peng et al. 2021; Li et al. 2022). Because other types of lithium batteries contain elements such as cobalt, the monetary value of recycling them is higher, making recycling of these batteries more profitable than LFP batteries (Alexander et al., 2021).

3.8. System Map

To better understand all the stakeholders involved in Spark's business in Liberia, we produced a System Map, shown in Figure 2. Here relevant participants in the process and their relationships are depicted using connections: Material Flow (blue), Financial Flow (red), and Information Flow (green). The complete map with a description of each actor and their connection is available in Appendix VI.

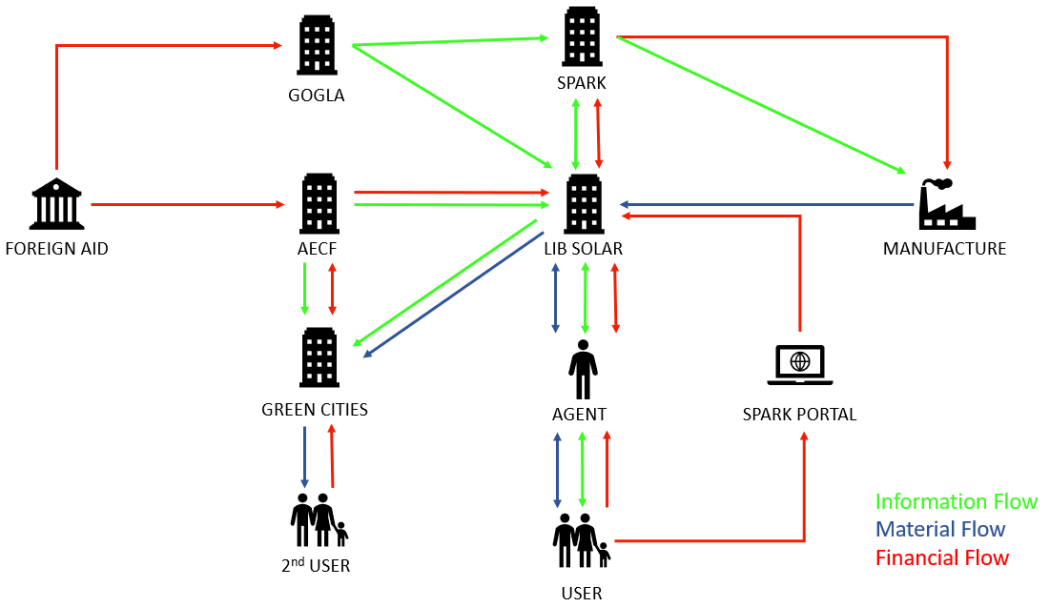

Figure 2 - System Map

4. Business Proposal

In this section, different parts of the business proposal are discussed. The first part details how Spark could increase communication with their partners. The following section proposes how Spark could become a more active actor in forging international relations related to solar energy. Lastly, suggestions are made for the new business proposal with respect to the national context, and the business proposal section concludes by presenting the new Business Model Canvas.

4.1. Communication with partners

Spark must have regular communications with its partners (i.e., national distributors) to avoid situations like the lack of knowledge of the existing relationship between the distributor LIB Solar and the recycler Green Cities at the beginning of this project. Since both parties have already signed an agreement to an EoL pilot towards the end of 2023 (Lidow, personal communication, 2022, October 11), the best strategy for Spark seems to be to get involved in this project by reinforcing the relationship between the parties and closely following the pilot project's development. Spark should also evaluate the pilot project regarding the success of the LIB Solar incentives (one free month of subscription) to the end-user; participate in the take-back system; the end-user fidelization rate (e.g. does the end-user replaces the old for a new battery pack or just downgrades the system); the logistics timings (e.g. how long does the customer take to report a dead battery; how long does the battery pack takes to reach to recycler centre); among other important parameters. This pilot is a good opportunity to develop a strategy that might be applicable in other markets and to mitigate eventual challenges for the future.

4.2. Operating in international relations

Spark should become an active actor in the international and national networks related to solar energy, electronic waste, circular economy, climate change mitigation and the achievement of the Sustainable Development Goals (SDGs). The international solar power companies may have a considerable positive influence in supporting the development of e-waste policies in their countries of activity (Manhart et al., 2018). Also, GOGLA argues that government regulation is necessary, especially when the waste product has a negative financial value like the LFP batteries, since there is no economic incentive for the private sector to take care of the e-waste end-of-life. Nevertheless, the promulgation of e-waste specific regulations could enforce new partnerships in the sector, increase rates of e-waste treatment and dilute costs amidst parties (Corbyn et al., 2019). Furthermore, there are coalitions and international funding concerning the greenhouse gases reduction and the achievement of SDGs by 2030. Regarding the latter, a good e-waste management directly contributes to SDG 12, on responsible consumption and production, that has a target 12.5 to substantially reduce waste generation through prevention, reduction, recycling and reuse in which an important indicator is the national recycling rate (CLASP, n.d.).

4.3. Operating in National Context

4.3.1. Future extended producer responsibility policy

In a country like Liberia, with almost no policy or infrastructure, Spark can only make a change if the change is embedded in the value network. Political power is required to lobby for a future policy containing Extended Producer Responsibility (EPR). Fundings are crucial to aid the governments in developing the needed structures, with several industry partners ready to collaborate and mitigate the related risks and costs.

4.3.2. National End of Life Management

The negative economic value of the LFP batteries might pose a challenge in the short-term. Currently, the recycler Green Cities in Liberia is able to receive Spark's spent batteries without any costs for the distributor LIB Solar. This offers a great opportunity for Spark as the EoL strategy requires minimum extra costs. However, due to the lack of response of Green Cities' CEO, the group couldn't gather information about the actual processes used by this recycling centre. Therefore, Spark should investigate the recycler's processes and evaluate the environmental impacts. Spark may look for collaborations with nearby markets, if the used methods are not up to the desirable quality. For instance, using Hinckley in Nigeria who was the 2019 winner of the Global LEAP Awards for the Solar E-waste Challenge (Global LEAP Awards, 2020). Furthermore, the recycling of other materials in the battery pack, like the plastic (ABS - acrylonitrile butadiene styrene) case, or other short lifespan products such as the Spark lamps should be more researched since they might have a better financial value that could balance out the LFP batteries. Also, in the Liberian case, there is a great lack of information regarding the energy access and use which could be explored as a new revenue stream especially since the energy consumption is monitored in real-time through the Spark portal.

4.3.3. Consumer Education

As mentioned previously, most end-users are not usually informed regarding the proper use, maintenance, and disposal of the products. In addition, there is a real challenge of hibernation due to the developed attachment between end-users and non-functioning products. Unfortunately, these challenges burden Spark's customers, the distributors, and threaten the success of the EoL strategy. Hence, there are three ways to improve this scenario: the creation of an intuitive mostly visual user guide (easily understood independently of user level of education) to be delivered with the new Spark products and published online in the Spark Portal; training the technical staff to provide an explanation to the end-user during the product installation; and a marketing campaign (e.g. radio adverts; participation on a local radio show; via text message) focus on EoL for the already existing end-users that might be harder to reach out to. There are several basic maintenance tips that can make a difference such as; keeping products clean, free of dirt and corrosion at all times, protect products from extremes temperatures, allow a full charge on new batteries before first use, avoid discharging batteries below 80% of their rate capacity (translate this info to what end-user can see in the battery pack display); use the system only with the proper appliances; teach end-user what are the signs of anomaly for the battery; amids other tips and tricks (CLASP, n.d.)

4.4. New Business Model Canvas

All above mentioned insights are summarised in a new Business Model Canvas (Figure 3), where Spark is more involved and present throughout their products life cycle inspired by EPR. Spark will, in this model, have international funding organisations as key partners and actively support the creation of e-waste management systems and policy frameworks in African countries in which it operates, e.i. GOGLA, existing national recycling centres or initiatives and strong relationship with the distributor which Spark already thrives for.

Spark's value proposition towards existing or future distributors should become more holistic, adding an EoL Management Strategy to the already important user-fit product portfolio (Spark Kits), the cloud-based payment system (Spark Portal), the distributor funding schemes (Spark Invest), the technical support and staff training. This would create possibilities for external funding to compensate for the negative value of the LFP batteries.

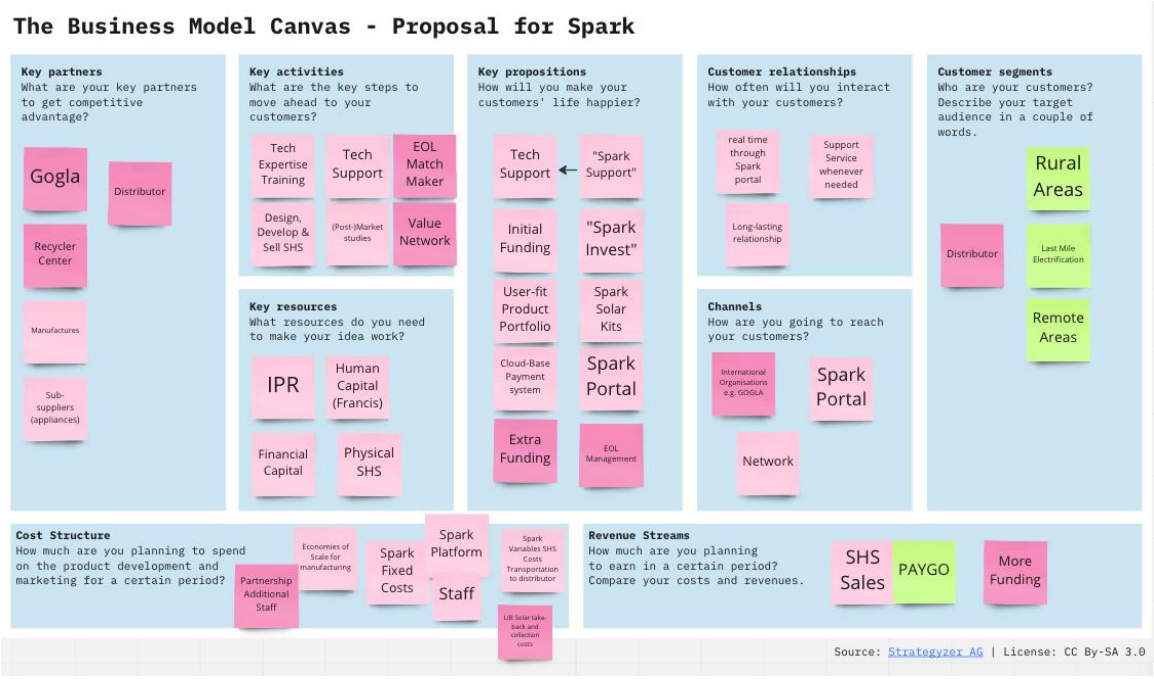

Figure 3 - New Business Model Canvas

This proposal requires new partnerships due to the absence of e-waste infrastructure and legislation in Liberia (and eventually other Spark markets), posing a significant challenge to any attempts of the company to establish a long-lasting EoL strategy for their products according to their vision, mission and values.
The legal landscape of Africa is changing rapidly with an increase from three countries covered by e-waste legislation, policy or regulation in 2018, to thirteen in 2020 (Maes & Preston-Whyte, 2022). Moreover, the conventions enforcement and the need of recycling infrastructure lacks public funding in Africa. This opens the possibility to public-private-partnerships between international players like GOGLA and companies like Spark.
The potential of waste from electrical and electronic equipment (WEEE) recycling and the mitigation of urban mining and waste burning are two important factors for Liberia's greenhouse gas reduction targets and climate-change mitigation plans. Therefore, this could be included in the call for financial assistance from parties, such as the United Nations or future partners outlined in Appendix VII, to cover some of the costs related to establishing and maintaining a WEEE management system (Maes & Preston-Whyte, 2022). Lobbying for EPR schemes in countries like Liberia may produce legislation providing a competitive advantage to regulated products such as Spark SHS and foster stakeholder partnerships to increase recycling capacity (Maes & Preston-Whyte, 2022).

5. Recommendations for Spark

Based on the business research and proposal, a roadmap has been created outlining the various steps that would enable Spark to establish its EoL management system in Liberia and other markets in which they operate. The section is divided into a roadmap for Libera and a generic one.

5.1. Roadmap for Liberia

The following roadmap is proposed for the Liberia case-study:

5.1.1. Awareness campaign

Raising awareness through targeted communication can delay the end-of-life of products and ensure their correct disposal. It is often framed in terms of reducing adverse effects on the environment and health. However, negative perceptions of these electronic goods must also be avoided, since this is counterproductive to environmental and social goals (Corbyn et al., 2019-3).

The proposed awareness campaign has two specific goals:

1) To promote proper use and maintenance of the battery to delay end-of-life.
2) To promote correct end-of-life disposal.

The first goal is to inform the end-users on how to treat the products and what to do in case of any faults. This will extend the product's life and hence reduce the adverse effects of improper end-of-life management. To promote the correct disposal of EoL batteries the end-users need to be informed about:

- Any potential incentives for returning spent batteries (e.g., discounts on a new battery)
- The lack of monetary and functional value of the spent batteries
- Dangers and health risks associated with keeping the spent batteries
- The impact incorrect management of spent batteries have on their immediate environment

The message can be communicated through a variety of channels, the most effective would be to utilise all the following. Firstly, through community agents the message can be spread during contact moments, such as delivering, installing, and maintenance of the products. Secondly, the Spark Platform allows building a relationship with the customer and communicating information (Corbyn et al., 2019-3).

5.1.2. Proactive partnerships

Our group suggests Spark should become a proactive partner in the relationship established between LIB Solar and Green Cities, by having a meeting with both partners to understand the conditions of the signed agreement. Moreover, Spark should investigate the methods used by Green Cities to refurbish or recycle the LFP batteries.

Relationships like that might be the answer for EoL management in the Liberian market, but Spark should be an active party to monitor the activities between their distributor and potential recyclers. Furthermore, they could help Green Cities to develop their network and business model by facilitating contact with similar international partners (e.g. Hickney in Nigeria). Due to lacking e-waste management it is essential to ensure that there is a functioning collaboration between Spark and LIB Solar.

5.1.3. Evaluating the pilot

The pilot collaboration between Lib Solar and Green Cities, offers a good opportunity to test incentives aimed at the end-user, and the quality of the take-back system. This would allow an expansion of the system to other markets, if successful.

5.2. General Roadmap Proposal

Learnings from the case-study are used to form a generic roadmap, outlined in the following sections, are applicable to existing and future markets.

5.2.1. Create an EoL management strategy for each market

A first step could be to produce an assessment per country including: EoL stock estimation based on current and forecasted sales, geographical dispersion, lifespan of products and state of the art recycling methods for each kit component (Magalini et al., 2020). Such analysis provides an overview for the

logistics needs regarding the take-back systems and second life possibilities. This could be done using the GOGLA circularity toolkit (https://www.gogla.org/circularity/tools).

5.2.2. Consumer education

The low monetary value of recycled LFP batteries requires consumer awareness about usage, maintenance and repair of the products to extend their lifespan, for as long as possible (Magalini et al., 2020). Therefore, the training provided to distributors' staff should include consumer education about all products' life stages. This information should be given during the sales, installation process, and provided at the Spark Portal.

5.2.3. Mobilise and be an active partner in international and national networks

Participating in international and national industry associations can facilitate exchanging of ideas and initiatives for e-waste management and policies (Magalini et al., 2020). Being an active partner in these associations may develop new relationships and increase opportunities for funded waste management projects by government or international donors (e.g., EU, GEF).

5.2.4. Support research on LFP batteries second life

LFP batteries are considered the best for static storing due to their longer lifespan, high fire safety and minimal environmental hazard potential in case of improper disposal in a landfill. However, the current recycling methods are not profitable for this specific type of battery. Therefore, a potential partnership with university research for the development of new lithium recovery methods could improve the situation. Furthermore, the electric vehicles industry is concentrating most of their research efforts on the development of more efficient and sustainable batteries. Their knowledge or even a cooperation with them could bear benefits for the solar energy sector.

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7. Team experience and lessons learned

7.1. Team Organisation & Roles

Concerning the organisation, our group met weekly on Monday during the lecture time (10:45 – 12:45). During this time slot, we defined the tasks that need to be done during the week and who performs them such as writing emails, performing interviews, performing research on a specific topic, preparing the presentation. We didn't specify clear roles as each one was equally invested in the project. We also scheduled three meetings with our challenge owner early on and reached out to her whenever we had questions. In the last three weeks, the final phase of the project, we met at least twice a week as a team, because more tasks had to be coordinated and discussed together.

7.2. Tools

To better organise ourselves and structure our work we used different tools. First, we used Microsoft Teams for our online meetings and interviews. Furthermore, we utilised Google Drive to store and share documents. To get an overview of who is currently working on which task we used the project management tool Trello. Finally, for brainstorming and working together on tasks such as the business model canvas we used the visual collaboration platform Miro.

7.3. Learning experience

During the projects, we learned a lot about the country of Liberia, its living conditions, and the market there. Furthermore, we found out that there is not a lot of literature about the country and interviews were crucial to understanding the context and conditions there. In addition, we learned how to analyse a business thoroughly and make meaningful suggestions. Our team got to know different models, strategies, and their advantages and disadvantages. We also strengthened our abilities to work in a team, coordinate team members, and work under time pressure and on multiple tasks in parallel.

7.4. Missing skills

Because our challenge focused on the recycling of batteries, a member in the field of chemical engineering or with knowledge about batteries and their recycling possibilities would have been helpful. Also, someone speaking one language of rural Liberia would have been beneficial as it would have been possible to conduct interviews with the end users of the Spark products.

7.5. Handling Conflicts and Decision Making

We didn't have many situations where we had conflicts or struggled with decision-making. Normally, a team member would propose an idea and argue for it. If another team member disagreed, he/she made arguments for his/her point, and then the team agreed on one of these ideas. As every team member was open to change and listened to new arguments, we always had open and factual conversations and debates. If that wouldn't have been the case a majority vote would have been a final option.

Appendix I - Spark product Kits

Spark product overview, Spark start (left) and spark supreme (right; Spark, n.d.)

Appendix II - PESTEL Analysis

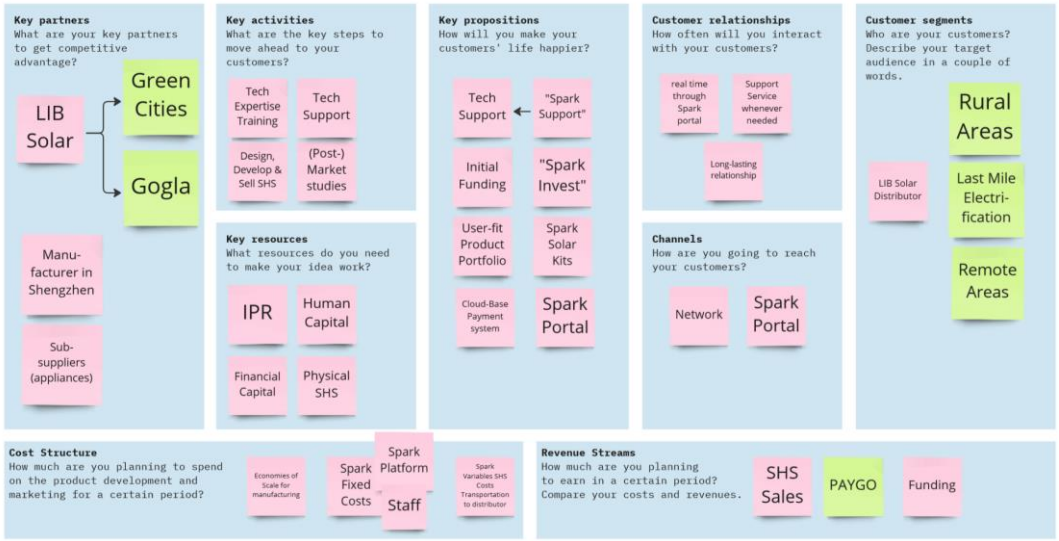
Political Factors	
Political environment	After 14 years of Civil War (1989-2003) (Wesseh & Lin, 2015), the first successful democratic transfer of power was in the 2017 presidential election won by George Weah with the next election is scheduled for 2023 (CIA, 2022). The current government has proposed a pro-poor agenda for prosperity, development and economic growth but widespread poverty and high inflation have been major obstacles (David et al., 2020).
Corruption	In 2021, the Liberia's Corruption Perception Index (CPI) revealed a score of 29 out 100 for Liberia, below the Sub-Saharan countries average score of 33, which places the country in 136th rank out of 180 countries. This info means that the public sector in Liberia is widely regarded as corrupt (Transparency International, 2021)
Economic Factors	
Currency	Liberian (LDR) and American dollars (USD) are recognised as legal money under the country's fluctuating exchange rate regime. The conversion or transfer of investment capital, profits, loans, and interest is currently unrestricted (USAID, 2020).
Partners	The main 2019 Export Countries are Guyana (32%), Poland (10%), Switzerland (8%), Japan (7%), China (5%) (CIA, 2022). The main 2019 Imports are from China (41%), Japan (21%) and South Korea (18%) (CIA, 2022).
Poverty	It is estimated that 34.6% (2022) of the Liberian population is living in extreme poverty below the international poverty rate of $2.15 per day (World Bank, 2022).
Unemployment rate	The unemployment rate was 4.1% in 2021 (World Bank, 2022)
Foregin aid and remittances	Being a low-income nation, Liberia depends heavily on aid from other countries and remittances from its diaspora community (CIA, 2022).
Mobile money	In Liberia, the use of mobile money has increased over the past five years, and it is anticipated to eventually supplant

	checks as the main method of non-cash currency exchange (USAID, 2020). LRD is used in the majority of mobile money transactions rather than USD, illustrating the prevalence of mobile money in the informal economy (USAID, 2020).
Beyond the grid fund Africa	The organisation announced a program in Liberia, to promote energy access using off-grid energy solutions with EUR 6.7 mio (BGFA, 2020).
Social Factors	
Demographic distribution	Liberia's age pyramid is remarkably youthful with 43% of the population aged 0-14, a median age of 18 years and only 6.3% of the population older than 55 years (CIA, 2022). This development is also fueled by the high fertility rate of nearly 5 children per woman (CIA, 2022).
Ethnographic and language	Liberia is one of the world's most ethnically diverse countries, with 28 ethnic groups. The three largest are Kpelle (20.3%), Bassa (13.4%), and Grebo (10%). The most common language is English, which covers only approximately 20% of the population. In addition, 20 ethnic groups have their own language, only a few of which can be written or used in correspondence (CIA, 2022).
Level of illiteracy	In 2017, there was an illiteracy rate of 51.7% among those over the age of 15, with males having a rate of 37.3% and females a rate of 65.9% (CIA, 2022).
Level of urbanisation	Currently 53.1% of the population lives in urban areas, the annual change rate is 3.41% (CIA, 2022).
Technological Factors	
LFP Battery	Main Unit Battery Chemistry of Spark Kit: LiFePO4 Li: Lithium, Fe: Iron, P: Phosphorus, O: Oxygen → Lithium-Iron Phosphate battery (LFP) The LFP batteries are the most common choice for solar home systems due to their long service life, deep-cycling ability, high current rating and good thermal stability, which usually results in little need for regular repair and maintenance and, also, good safety and resilience at high temperatures in Africa. LFP has a major drawback which is the low value of the materials comprising the electrodes which results in little recycling value (Alexander et al., 2021). LFP batteries do not contain nickel, cobalt or rare earths which are economically significant for recycling. In LFP batteries the concentrations of lithium are around 1%, while copper concentration lies between 7%- 8%. By established

	recycling processes, less than 10% of LFP batteries can be recycled which causes net-costs as high as 2,500€ – 3,500 €/ton. In case there are no collection and treatment efforts financed by other means than raw material recovery, these batteries will most likely be managed mixed municipal solid waste (landfill disposal, open burning, etc.)(Manhart et al., 2018).
Infrastructure	From 1985 until 2003, Liberia endured civil war, which destroyed 75% of the country's transportation and electricity infrastructure. Including much of the infrastructure in and around the capital. Liberia has been striving to repair this infrastructure since the civil war ended (USAID, 2020; CIA, 2022).
Electricity grid	At maximum capacity, Liberia's national grid is expected to reach only 35% of the population by 2030. (USAID, 2020). The current national average is 12%, with urban areas being 18% and rural areas 6%. (2019; CIA, 2022).
Environmental Factors	
Pollution	Despite the absence of heavy metals in Li-ion batteries, there are still constituent parts with potentially negative effects on human health and ecosystems such as its plastic casing, circuit boards and cables. Although the LFP batteries toxicity potential is significantly lower compared with other batteries, the little recycling value might increase the likelihood of uncontrolled battery disposal in the environment (Manhart et al., 2018).
Climate and Weather	Liberia is a very rain-heavy country which makes logistics challenging. The capital, Monrovia is one of the wettest capitals of the world with an average annual precipitation over 5000mm (Rainfall – Liberian Hydrological Services, 2022). As a reference, the city of Eindhoven has an average precipitation of 750mm (Climate - Eindhoven (Netherlands), 2022).
Infrastructure	In Liberia, there are only three paved roads outside the capital with the rest being dirt roads quickly turning into rivers with heavy rainfall. Also, people rely on handmade fairies to cross rivers because often there are no bridges (LIB Solar, 2020).
Waste System	The only Liberia waste system is the Municipal Solid Waste Management System (MSWM) in the capital Monrovia which is describe in literature as appalling due to shortage of a comprehensive waste management framework, the absence of guidelines regarding the responsibilities of waste generators, and the decision-makers' lack of intent to design and implement a sustainable and integrated management system. The consequences of an unsustainable solid waste management in urban areas and its absence in rural areas include land degradation, breeding sites for mosquitoes and other vectors, diseases, impact on land valuation, and illnesses (David et al., 2020).
E-Waste	Within Africa, close to e-waste

	processing sites, toxic elements, persistent organic pollutants (POPs), and heavy metals have been observed in elevated levels in dust, soils [30–33] and vegetation, including edible plants [34, 35]. Further environmental effects have been observed because of higher metal and rare earth element (REEs) [36] concentrations in downstream aquatic and marine environments, causing adverse marine consequences including smaller, sicker, and sparser fish stocks Current e-waste processing in Africa has the potential to impact the ozone layer and climate change. Open burning, not only releases toxins but also carbon dioxide (CO_2).
Legal Factors	
Liberian Environmental policy	Section 5.7 on waste management and sanitation states that all wastes should be disposed of in a manner that does not harm the environment. Furthermore, the strategic policy measure of encouraging waste reduction and recycling is suggested (LMFA, 2002).
Environmental Protection and Management Law of Liberia	Section 55 prohibits importation and exportation of hazardous waste, Section 62 prohibits solid waste pollution, and Section 64 outlines the application and guidelines for obtaining a solid and hazardous waste disposal license (LMFA, 2003).
Basel Convention	The Basel Convention is intended to ensure environmentally responsible management of the waste close to the source of generation and to reduce the movement of hazardous waste between countries, particularly from developed to less developed countries (Basel Convention, 1989)
Bamako Convention	The Basel Convention failed to effectively forbid the trade of hazardous waste into Africa, leading to the creation of the Bamako Convention. This agreement is more strict in preventing the import of any hazardous waste (Bamako Convention, 1991)
Rural & Renewable Energy Fund	In the executive order the Liberian government reconfirms that energy produced using locally renewable resources such as solar power is supported financially to ensure their capability of meeting their responsibilities under United Nation Framework Convention for Climate Change (UNFCCC; Sirleaf, 2012)

Appendix III - Current Business Model Canvas



Key partners: As key partners, we identified Sparks Manufacturer in Shenzhen (China), the sub-suppliers of appliances (Radios, TVs,...), and LIB Solar. LIB Solar distributes Sparks products in Liberia, handles logistics in the country, and end-user interactions. Through LIB Solar, Spark has also indirect partnerships with the local recycler Green Cities and the global association for the off-grid solar energy industry (GOGLA). More details about LIB Solar, Spark's main partner in Liberia, are described in the next sections.

Key activities: Spark offers tech expertise through training, tech support for its customers, and market studies. Their main activity is the design, development, and selling of solar home systems.

Key resources: Spark's key resources are the solar home systems combined with an IPR. Furthermore, Spark has Human as well as Financial Capital.

Key proposition: Spark sells modular solar kits, which means people can connect and combine them as they like. Moreover, Spark offers a portal that enables a pay-as-you-go payment system. Another proposition is "Spark Invest" through which distributors can buy Sparks products and pay up to three years later. Finally, spark offers technical support for the products and offers to train employees of their distributors.

Customer relationship: The company interacts with its customers in real time through its platform called Spark portal. Moreover, they offer a support service whenever needed and build long-lasting relationships with their partners and customers.

Channels: Spark interacts with its customers through the Spark portal and its partner network.

Customer Segments: Because Spark is a B2B company its main customers are distributors delivering solar home systems to rural, off-grid communities in African countries.

Cost structure: Spark has costs to produce its products and ship them to Africa. Moreover, their platform and employees also produce expenses.

Revenue streams: Spark's main revenue stems from the sale of solar home systems and appliances to distributors in Africa. Also, the company receives funding.

Appendix IV - LIB Solar

LIB Solar's selling process

The selling process includes the following steps in the following steps:

1. First, a sales member of LIB Solar hosts a meeting with all members of a rural community. There, the products are showcased and explained to the inhabitants.
2. LIB Solar then only sells to this specific community if at least 25 households agree to purchase their products. Furthermore, a person from the community must agree to act as an "agent" for LIB Solar.
3. This community agent is then trained and performs tasks such as collecting payments and basic maintenance.
4. LIB Solar also enforces community pressure. This happens if one customer does not pay. Then, the electricity of the whole community is shut off until the payment is collected.
5. Finally, through data collection and the local agent, the company tries to identify new business opportunities and customers.

The whole process is summarised in the following graphic:

Source: (*LIB Solar*, 2020)

Moreover, it is worth mentioning that LIB Solar's customers own their systems after completing a series of payments (approximately after three years). Also, the community's payment history combined with other data serves as a credit score that can unlock additional financing for goods, business equipment, infrastructure, and loans (LIB Solar, 2020; GOGLA, 2018; AECF, 2021).

Current Repairs

Currently, the systems haven't reached their end of life yet. However, sometimes technical failure of some parts occurs. The part which is most prone to that is the light switch and after that the battery. Both parts can be changed easily without needing to replace the entire system and the replacement can usually be made in less than 24h. A member of the field staff collects the faulty device and installs a substitute. Furthermore, the employee delivers the faulty part during the next trip to the Head Quarter where the part can either be repaired or stored safely in an insulated shipping container. Other challenges mentioned by LIB Solar's customers are sometimes unreliability issues, payment delays, and a low battery and charging capacity which could stem from production errors (N. Lidow, personal communication, October 11, 2022).

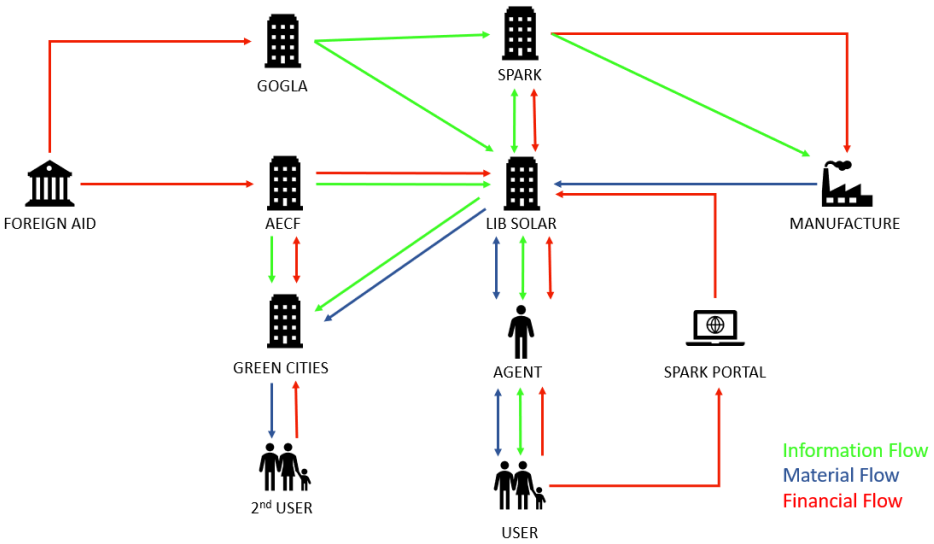
- Logistics for take-back

LIB Solar's business model makes product take-backs easy as they use the same methods for installing products, repairing,and taking them back. Because in each community an agent is present, the customers can hand their broken system to the local agent. Then, each community is visited at least once per month by a full-time staff member who can collect the devices and bring them to the headquarters (F. Williams, personal communication, October 14, 2022)**.**

Appendix V - Barriers to OGS EoL

Source: (Rhodes et al., 2020)

Appendix VI - System map



FOREIGN AID: This stakeholder summarises different governments, organisations and funds providing financial aid to the global association for the off-grid solar energy industry (GOGLA) and the African Enterprise Challenge Fund (AECF).

GOGLA: An international organisation for the off-grid solar energy sector that promotes off-grid solar and efficient appliances while highlighting the benefits of off-grid solar systems (GOGLA, 2016). GOGLA provides documents, toolkits and vital information to companies operating in Liberia such as SPARK and LIB SOLAR.

AECF: An African challenge fund established by developed countries to improve the private sector in Sub-Saharan Africa (AECF, n.d.). AECF supports responsible companies located in Africa (i.e., LIB SOLAR and GREEN CITIES) with financial means and information.

SPARK– Spark Energy: A Dutch energy company that develops and sells B2B products. The products are produced at a MANUFACTURE in China (Shenzhen). Spark's distributor in Liberia is LIB SOLAR with whom the company exchanges information and sells their products to.

MANUFACTURE: Spark's product MANUFACTURE is located in China (Shenzhen). The products are directly sent from China to Spark's Liberian distributor LIB SOLAR.

LIB SOLAR: The company buys products from SPARK and distributes them through AGENTS to the end-USERs. Payments from the USERs can be collected through the website SPARK PORTAL. If a product needs to be replaced the AGENTS collect them from the USERs and bring them back to LIB SOLAR's headquarters.

GREEN CITIES: A Liberian remanufacturer, refurbisher, and recycler with the goal of addressing E-Waste Management. The company has a focus on providing solar energy wastes a second life (GreenCities, n.d.). The company has an agreement with LIB SOLAR, which states that the recycler collects waste from LIB SOLAR without receiving a payment. However, they can sell the recycled/refurbished products to their own 2nd USERS.

Appendix VII - Future partners

Name	Lender	Country	Description	Instrument	Fund size Min	Fund size Max	Area	Focus	Currencies	Website	Email
A/B Loan Programme	FOM	Nederlands	A Dutch entrepreneurial development bank with investments that span 85+ countries supporting job and income generation by helping businesses operate and grow transparently in an environmentally and socially responsible manner.	Debt	1 - 3 mil.	n.a.	Global	Mini Grids, Solar Home Systems, Independent Power Producers, Commercial and Industrial (on-site power/heat generation)	GBP, USD	link	info@fmo.nl
Access to Clean Power Fund (ACPF)	responsAbility	Switzerland	Provides debt financing to entities operating across the entire energy sector value chain. Senior and subordinated (secured and/or unsecured) corporate loans are provided. Other structures such as special purpose vehicles (off-balance sheet transactions) are also considered.	Debt	1 - 3 mil.	10 mil.	Sub-Saharan Africa & Asia	Mini Grids, Solar Home Systems, Independent Power Producers, Commercial and Industrial (on-site power/heat generation)	EUR, USD	link	energy@responsability.com
Acumen Resilient Agriculture Fund (ARAF)	Acumen Capital Partners	Kenya	An equity fund designed to build the climate resilience of smallholder farmers. ARAF invests in early and early-growth stage agribusinesses that produce, sell or utilise renewable and agricultural productive-use technologies	Equity	n.a.	n.a.	Sub-Saharan Africa	Solar Home Systems, Argi-productive use	EUR, USD	link	info@arafund.com
Africa Renewable Energy Scale-up Facility (ARE Scale Up)	Société de Promotion et de Participation pour la Coopération Economique (Proparco)	France	Provides guarantees to support equity investments in off-grid, mini-grid and other decentralised solutions as well as technical assistance for beneficiary companies and for the implementation of the guarantee component.	Guarantee	n.a.	n.a.	Sub-Saharan Africa	Mini Grids, Solar Home Systems, Argi productive use	n.a.	link	proparco@proparco.fr
AlphaMundi Foundation	AlphaMundi Foundation	USA	Offers grant funding, which is tied to the Powering Agriculture Investment Alliance. AlphaMundi also provides subsidised technical assistance for businesses providing clean energy solutions that increase agriculture productivity in developing countries.	Grant	5,000	50,000	Kenya, Rawanda, Tanzania, Uganga, Zambia	Mini Grids, Solar Home Systems	USD	link	info@alphamundi.ch
Beyond the Grid Fund for Africa (BGFA)	Nordic Environment Finance Corporation (NEFCO)	Nordic	A multi-year funding facility aiming to kick-start markets for clean, off-grid energy in Sub-Saharan African countries. It works through a combination of an innovative results-based financing mechanisms for energy companies, close cooperation with governments and real-time data collection and analysis.	Grant	> 1,000,000		Burkina Faso, Liberia, Mozambique, The Democratic Republic of Congo, Uganda, Zambia	Mini Grids, Solar Home Systems	EUR	link	ash.sharma@nefco.int
Business Development Support Fund (BDSF)	Belgian Investment Company for Developing Countries (BIO)	Belgium	Offers grants and co-finances technical assistance, feasibility studies and investment support for innovative small and medium-sized enterprises.	Grant	50,000	200,000	Sub-Saharan Africa, Asia, Latin America, Northern Africa, Middle East	Mini Grids, Solar Home Systems	EUR, USD, National	link	info@bio-invest.be
Convertible Grants	DOEN Foundation	Nederlands	Offers grants for supporting a green, socially inclusive and creative society. Distinguishes between types of grants based on the scale of the project or type.	Convertible Grant	200,000	500,000	Ethiopia, Kenya, Rawanda, Tanzania, Uganda	Mini Grids, Solar Home Systems, Argi productive use	EUR, USD, National	link	mireille@doen.nl
D-Prize	USA	USA	Funds pilot projects that distribute low-cost products and services by awarding teams with grants to launch non-profits or social ventures that can distribute proven poverty alleviation interventions to people in need.	Grant	5,000	50,000	Global	Mini Grids, Solar Home Systems	USD	link	hello@d-prize.org
DeveloPPP	DEG	Germany	Programme supports companies that wish to operate in emerging markets on a long-term basis.	Grant	50,000	> 1,000,000	Global	Mini Grids, Solar Home Systems, Argi productive use	EUR	link	developpp@deginvest.de
EDP Access to Energy (A2E) CSR Fund	Energias de Portugal (EDP)	Spain	Supports sustainable and clean energy projects in developing countries in various sectors, including water and agriculture, community and small businesses, health and education.	Grant	50,000	200,000	Eastern Africa, Southern A	Mini Grids, Solar Home Systems	EUR	link	paulocampos.costa@edp.com
EEP Africa Innovation Window	Nordic Development Fund (NDF)	Nordic	Innovation window provides early-stage grant financing for innovative clean energy projects in active development through competitive calls-for-proposal. Companies, start-ups and social enterprises are eligible to apply, and the project must be implemented in one or more of the 15 countries in East and Southern Africa covered by EEP Africa	Grant	200,000	500,000	Eastern Africa, Southern Africa	Mini Grids, Solar Home Systems, Argi productive use	EUR	link	info@eepafrica.com
EnAccess	EnAccess	Nederlands	Funds open-source solutions for energy access through Innovation Pilots and "Moonshot" concepts.	Grant	5,000	500,000	Global	Mini Grids, Solar Home Systems, Independent Power Producers, Commercial and Industrial (on-site power/heat generation)	USD	link	info@enaccess.org
Institutional Grants	DOEN Foundation	Nederlands	Offers grants for supporting a green, socially inclusive and creative society. Distinguishes between types of grants based on the scale of the project or type. Institutional grants are financial donations to support organisations as a whole.	Grant	50,000	200,000	Ethiopia, Kenya, Rawanda, Tanzania, Uganda	Mini Grids, Solar Home Systems, Argi productive use	EUR, USD, National	link	mireille@doen.nl
Off-Grid Market Development Fund (OMDF)	Bamboo Capital Partners (BCP)	Luxembourg	Offers subsidies to distributors of qualified products. Participating companies receive a results-based financing (RBF) subsidy for each qualified solar product distributed in Madagascar, which is disbursed after the reporting and verification of sales.	Grant			Madagascar	Solar Home Systems	USD, National	link	contact@omdf.mg
Sustainable Energy Fund for Africa (SEFA)	African Development Bank (AfDB)	Côte d'Ivoire	Provides technical assistance and concessional financing to remove market barriers, build a more robust pipeline of projects and improve the risk-return profile of individual investments.	Grant	500,000	1,000,000	Sub-Saharan Africa, Northern Africa	Mini Grids, Solar Home Systems, Argi productive use, Public Facilities	USD	link	SEFA.applications@afdb.org
United Nations Capital Development Fund (UNCDF)	UN	USA	Offers performance-based grants deployed through request for applications or challenge calls.	Grant	50,000	500,000	Sub-Saharan Africa & Pacific	Mini Grids, Solar Home Systems, Independent Power Producers	USD, National	link	info@uncdf.org
Upscaling Programme	DEG	Germany	Finances innovative pioneering investments of German and domestic small and medium-sized enterprises (SMEs) in developing countries.	Grant	500,000	1,000,000	Sub-Saharan Africa	Mini Grids, Solar Home Systems, Fintech, Green Tech	EUR	link	up-scaling@deginvest.de

Appendix VIII - Material overview

Battery	LFP-Graphite
Cathode	$LiFePO_4$
Anode	Graphite
Battery Cell Weight [kg]	0.086
Number of Cells per unit	4
Total battery weight per unit [kg]	0.344

Material Composition (mass %)'		Mass per module [kg]
Cathode active material	22.2%	0.07637
Anode active material	15.3%	0.05263
Electrode Elements		
Lithium (Li)	1.1%	0.00378
Nickel (Ni)	0.0%	-
Cobalt (Co)	0.0%	-
Aluminum (Al)	0.0%	-
Oxygen (o)	9.0%	0.03096
Iron (Fe)	7.8%	0.02683
Phosphorus (P)	4.4%	0.01514
Manganese (Mn)	0.0%	-
Titanium (Ti)	0.0%	-
Graphite (C)	15.3%	0.05263
Carbon	2.1%	0.00722
Binder	3.4%	0.01170
Copper parts	13.8%	0.04747
Aluminum parts	13.3%	0.04575
Aluminum casing	9.4%	0.03234
Electrolyte solvent	14.2%	0.04885
Plastics	4.6%	0.01582
Steel	0.1%	0.00034
Thermal insulation	1.3%	0.00447
Electronic parts	0.3%	0.00103

(Gaines and Burnham (2011)

Year	2022	2026	Total
Units introduced to Liberian market	30,000	72,000	102,000
	2,291	5,498	7,790
	1,579	3,790	5,368
	114	272	386
	-	-	-
	-	-	-
	-	-	-
	929	2,229	3,158
	805	1,932	2,737
	454	1,090	1,544
	-	-	-
	-	-	-
	1,579	3,790	5,368
	217	520	737
	351	842	1,193
	1,424	3,418	4,842
	1,373	3,294	4,667
	970	2,328	3,298
	1,465	3,517	4,982
	475	1,139	1,614
	10	25	35
	134	322	456
	31	74	105

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