IGC

State Fragility initiative

POLICY TOOLKIT

E-waste management: Strategies and policies in fragile contexts

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Electronic waste (e-waste) is the fastest growing waste stream in the world, with solar mini grid equipment and appliances that are run off mini grids constituting a growing portion of e-waste globally. Much e-waste ends up in low-income countries, including from second-hand imports, resulting in e-waste management becoming a growing issue for these countries. This toolkit outlines considerations for policymakers of fragile contexts as they embark on developing e-waste management systems in their countries.

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In this paper

This paper provides evidence to inform policy decisions around electronic waste (e-waste) management in fragile and conflict-affected situations (FCS). It is intended to help equip policymakers in fragile settings with an understanding of the key challenges facing governments in building the infrastructure needed to 'safely dispose of e-waste and approaches they can take to alleviate the negative impact of that waste. To lower the amount and harm of e-waste in fragile settings, collaborative efforts are required from a range of stakeholders, including donors, philanthropic entities, private manufacturers and energy project developers. Consequently, this paper outlines important lessons for other key stakeholders too.

The technological scope of this toolkit focuses on the e-waste generated from solar mini grids. However, as other electric and electronic equipment become more widely used following electrification, the toolkit also refers to other types of e-waste that accompany the deployment of solar mini grids, such as productive use of energy appliances.

List of abbreviations

Abbreviation	Meaning
EOL	End of Life
EMP	Environmental management plan
EPR	Extended Producer Responsibility
FCS	Fragile and Conflict-affected States
GOGLA	Global Off-Grid Lighting Association
ITU	International Telecommunication Union
O&M	Operations and maintenance
PV	Photovoltaic
PCB	Printed circuit boards
POP	Persistent organic pollutants
PPP	Public-private partnership
PRO	Producer Responsibility Organisation
PVC	Polyvinyl chloride
UNITAR	United Nations Institute for Training and Research
WEEE	Waste Electrical and Electronic Equipment
WHO	World Health Organisation

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Executive summary

Solar mini grids have a key role to play in ensuring clean energy access for all (Sustainable Development Goal 7). The World Bank estimates that in 2021, 19,000 solar mini grids were installed and another 30,000 were planned across over 130 countries. To reach universal electricity access by 2030 would require the development of a total of 210,000 mini grids.[1] Mini grids are particularly well suited for fragile and conflict-affected situations (FCS): they are more modular than national grid infrastructure and can be more easily deployed in hard-to-reach areas or fragile settings. The roll-out of mini grids is inevitably followed by the increased penetration of electrical and electronic equipment (EEE) within a country.

This increased access to EEE within countries raises the question of what should happen to this equipment once it reaches its end-of-life (EoL). An estimated 5.5-6 million metric tonnes of solar panels are expected to be decommissioned by 2050. E-waste is the fastest growing waste stream in the world, with 62 million tonnes of waste generated in 2022 and expectations that it will reach 82 million tonnes by 2030.[2] Less than a quarter of e-waste is recorded as collected and recycled through formal channels. Instead, a large portion of e-waste is dumped in landfills, burnt, or buried, with the informal sector repurposing what valuable materials they can find using crude recycling methods.

This improper disposal of e-waste creates a considerable threat to communities living near e-waste disposal sites. E-waste has been found to contain lead, mercury, cadmium, and nickel, as well as brominated flame retardants, all of which have detrimental impacts on human health. Lead is particularly hazardous for children, causing neurodevelopmental and behavioural challenges.

However, setting up the infrastructure and regulations needed to ensure the safe disposal of e-waste is a considerable challenge. Difficulties include:

- **Lack of financial incentives** – Disposing of e-waste properly is generally too costly even when valuable raw materials can be extracted. The high cost involved in picking up the used parts from remote areas and sending them to appropriate facilities where they can be recycled, together with the low volumes involved, means that it is generally prohibitively costly to do.
- **Insufficient infrastructure** – Many countries still lack solid waste management infrastructure, let alone facilities to recycle solar panels, circuit boards, and batteries. There is also a lack of collection points and storage facilities that are accessible for households and businesses to dispose of their e-waste. This is compounded by a lack of reliable road infrastructure in some countries, especially to more remote areas, making the transportation of e-waste more costly.

1 ESMAP, 2022.
2 UNITAR, 2024.

- **Undeveloped regulations** – Without government regulations, no stakeholder bears the legal responsibility to finance and operate e-waste management activities. Only three countries (Ukraine, Cameroon, and Nigeria) out of the 39 countries categorised as FCS by the World Bank have e-waste regulations in place. These regulations can be hard to establish, as there are several actors involved in the creation of e-waste (producers of each component, developers, and consumers in the case of mini grids). Even if regulations are adopted, they are hard to enforce as governments require capacity to set targets and monitor recycling value chains.
- **Lack of awareness** – Consumers generally lack awareness of the environmental and health problems caused by e-waste. They are also unaware of the best way to dispose of e-waste and where to find the facilities to do so.
- **Poor maintenance and repair** – Solar mini grids require consistent maintenance and repair to ensure that they reach their expected lifespan. This is costly to do, especially in remote areas or conflict zones. Obtaining spare parts is expensive, with most parts needing to be imported. Specialised labour is needed to ensure proper maintenance and repair and the local labour force often lacks the technical training necessary to do so.
- **Low quality and suitability of the solar mini grid** – Many solar panels break down before their EoL. Solar mini grids are sometimes built using cheap, ill-adapted, or second-hand components, leading to their premature EoL. Matching demand to supply is also crucial in ensuring the sustainability of the mini grid. If the demand is too low, the fees paid by the existing customers may not be enough to cover the maintenance and repair costs. If the demand is too high, the grid will be overloaded, which can lead to its premature wear.
- **Inadequate data** – Many countries lack robust data on the quantity of e-waste in the country and its composition, making it difficult for the government to design policies and regulations that effectively tackle the issue.

In FCS, this is compounded by security issues which increase the cost of collecting e-waste and maintaining the grid. Exchange rate fluctuations and depreciation of the local currency can make it more expensive (in local currency terms) to import the spare parts necessary for repair. Finally, poor governance and resource constraints mean that it is difficult for governments to build the infrastructure and regulations necessary to safely dispose of e-waste. Given the myriad of priorities facing FCS governments, building e-waste infrastructure seldom features on governments' agendas but, as the quantity of e-waste in a country rises, it will become an increasingly important issue.

Building on the literature on e-waste management in developing economies and several interviews with practitioners in this space, this toolkit explores potential pathways for governments of FCS to mitigate the impact of e-waste and to curb the increase in e-waste in their countries. It recognises the significant constraints that FCS face, including the difficulty of drafting and enforcing e-waste regulations in capacity-constrained contexts. Nonetheless, it draws on the experience of other countries to identify several pathways that FCS can adopt to tackle the rising challenge that e-waste poses.

The main recommendations of this toolkit are to:

- **Emphasise prevention** – As much as possible, governments and mini grid developers should minimise the e-waste generated by the grid and other EEE. E-waste prevention can take many forms: ensuring correct sizing of mini grids to ensure that they are not under- or over-used, designing the grid in such a way that it can be easily repaired, and undertaking regular maintenance of the grid to avoid premature failures. The quality of the grid needs to be high enough to avoid early dysfunction, which can often happen when the components are of poor quality or second hand.
- **Build basic recycling infrastructure for the most hazardous components** – Governments and developers can collaborate to start building basic recycling infrastructure: collection points, storage and transportation systems, and dismantling sites. This can be initially restricted to the most hazardous components (such as lead-acid batteries) or to components that are easier to recycle (such as copper cables).
- **Build on the informal recycling sector** – Most countries have an informal recycling sector that collects e-waste and recovers its most valuable parts. This is often done in a rudimentary way, endangering workers and communities alike. However, instead of suppressing this sector, governments can work with international actors and EEE manufacturers, using the informal sector and its network to collect higher volumes of e-waste. Training can be delivered to informal recyclers to increase their safety standards and protective equipment can be distributed. Financial incentives can be offered to informal recyclers to bring back the e-waste collected to proper treatment facilities. Over time, governments can start formalising these operations.
- **Collect data on e-waste** – Data is required to start regulating e-waste and building key infrastructure, but this is often missing in FCS. Governments can work with international organisations such as UNITAR to start building a database on e-waste within their country. Generally, this requires inputting import data into a lifecycle model to assess when EEE will reach their EoL. Capacity should be built within governments to start collecting data.
- **Start regulating as capacity increases** – To ensure that a sizable fraction of e-waste is safely disposed of, governments will eventually need to regulate it. This is generally done through an Extended Producer Responsibility (EPR) policy. This type of regulation puts the financial and sometimes operational responsibility for the safe disposal of e-waste on producers of EEE. This type of regulation takes time to be drafted and adopted, with many different public and private stakeholders needing to collaborate to ensure that each has a clear and accepted role to play. It also requires building the capacity of governments to monitor and enforce the policy. Governments can work towards this by mapping stakeholders, current regulations on hazardous waste, and projects on e-waste. As capacity builds over time, governments can then start drafting e-waste regulations with the help of international organisations.

1. Introduction

Solar mini grids have an essential role to play in providing affordable and clean energy within fragile and conflict-affected situations (FCS). Smaller and more modular than national grids, they are more suited to servicing hard-to-reach areas, providing electricity to many households and small businesses that the national grid has not been able to reach. In theory, solar mini grids are capable of lasting between 20 and 30 years and they can ensure a reliable and long-lasting power supply if they are well maintained and operated. The World Bank estimates that in 2021, 19,000 solar mini grids were installed and another 30,000 were planned across over 130 countries. To reach universal electricity access by 2030 would require the development of a total of 210,000 mini grids.[3]

However, the rapid deployment of solar mini grids and accompanying electric and electronic equipment (EEE) raises questions on what will happen to those products once they reach their end-of-life (EoL) and are decommissioned. Electronic waste, or e-waste, from solar panels alone are estimated to reach 5.5-6 million metric tonnes by 2050, compared to 43,500-250,000 tonnes in 2016.[4] Solar mini grids are complex systems: they are composed of solar panels, batteries, inverters, and electric cables. These components contain valuable metals, such as aluminium, lead, and copper, that can be recuperated and used for the manufacturing of new components. More importantly, they can also be harmful to local communities and to the environment if improperly disposed of. Exposure to minerals such as lead, cadmium, mercury, and nickel and to endocrine-disrupting chemicals found in e-waste is associated with poorer neurodevelopmental outcomes, behavioural abnormalities, and hormonal disruptions. Children and pregnant women are particularly at risk.

Disposing of solar mini grids in a safe and efficient manner is not an easy task. The costs of recycling solar mini grid components and batteries are high. Adequate recycling facilities are still rare, with few facilities for the recycling of solar panels and lithium-ion batteries having been established world wide. There are few financial incentives for private actors to invest in recycling facilities, as the cost of recycling often outweighs the price obtained for recovered materials. Transportation costs are also often prohibitively high, especially when the mini grids are located in remote areas. Consumers lack awareness on the environmental and health impacts of the improper disposal of e-waste, leading to poor disposal practices. Finally, the lack of regulations and policies imply that the legal financial and operational responsibility for the safe disposal of e-waste is not clearly assigned among stakeholders.

3 ESMAP, 2022.
4 IRENA, 2016a.

In fragile contexts, these constraints are compounded by security issues and the lack of road infrastructure to reach more remote areas. This makes it difficult to collect e-waste but also to maintain and repair the solar mini grid, often resulting in premature failure. There is also a lack of infrastructure in these countries to collect, recycle, and dispose of used equipment. Finally, the lack of government capacity, both in terms of financial and human resources, makes it difficult to regulate and monitor e-waste management.

Due to these complications, governments and developers rarely plan for e-waste management before deploying solar mini grids. As explained in other toolkits in this series, successfully installing a financially sustainable grid that can supply energy at low prices in remote areas is already very challenging, without the additional costs associated with e-waste management. Nevertheless, this toolkit argues that the earlier governments and developers incorporate e-waste into their considerations, the less severe the problem will become in the future. Preventing unnecessary e-waste through careful planning, maintenance, and repair is essential to reduce the quantity of e-waste governments will have to contend with in the future. This toolkit aims to offer practical advice to policymakers and developers on how to design and maintain mini grids to maximise their lifespan, and how to start setting up infrastructure and legislation to tackle the most hazardous fractions of e-waste. Over time, and as their capacity increases, policymakers can build on this effort to expand the scope of the policy and tackle less hazardous strands of e-waste.

FCS represent a broad range of countries with different levels of EEE penetration. Countries with still low levels of e-waste and investment in distributed renewable energy may want to focus on ensuring that the quality of EEE entering the country is high enough to avoid creating immediate issues with e-waste. As the stock of EEE and investment increases, governments should start to regulate e-waste and to develop basic recycling systems. Governments can lean on the technical assistance of international organisations working in this space and on the experiences of other countries to help develop the most appropriate strategy to manage their e-waste.

This toolkit is primarily aimed at policymakers, international organisations, and private developers deploying solar mini grids in FCS. It is mainly preoccupied with the waste generated from the solar mini grids themselves. However, given that electrification is generally followed by an expansion of electronics, it also considers broader electric and electronic waste.

2. The impact of e-waste

Electric and electronic equipment (EEE) is defined as “any household or business item with circuitry or electrical components with power or battery supply.”[5] EEE turns into waste electrical and electronic equipment (WEEE), or e-waste, when the items or parts are “discarded by the owner as waste without the intention of reuse.”[6]

Solar mini grids are composed of many different EEE. They include solar panels, inverters, cables, circuit boards, and most batteries. While the exact composition of the grid equipment varies depending on the types and quality of their components, they usually include glass, plastics, and several metals, such as aluminium and lead. Some of these materials are inherently harmful to the environment and human health. While in use, this is commonly not a problem, as the materials are contained within the components. However, this can become a severe issue when the components fall into disrepair and are disposed of improperly. Due to the hazardous nature of e-waste, it needs to be handled separately from general waste to ensure its proper treatment.

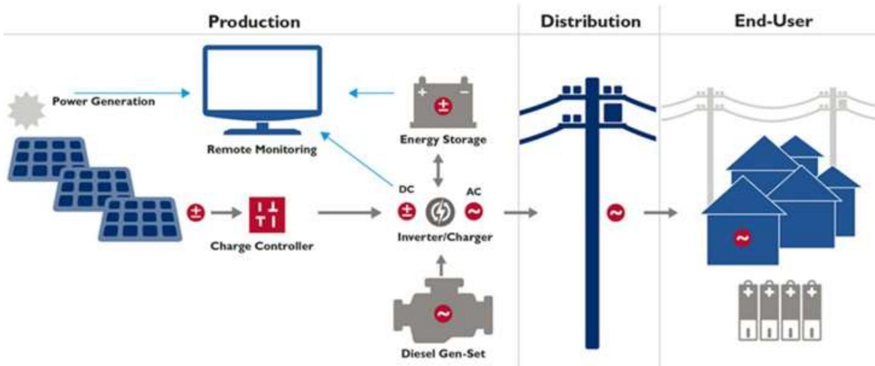
This section reviews the basic components of solar mini grids and their impact on health and the environment, the current common methods of disposal, and the potential for recycling each component.

2.1. Components of solar mini grids

Solar mini grids are composed of solar photovoltaic (PV) modules, inverters, a management system, a distribution system and, in many cases, batteries to store energy or diesel generators.[7] **Figure 1** illustrates the different parts of the solar mini grid. The first components are the solar panels, which generate electricity. Since solar electricity can only be produced during the day, solar mini grids need energy storage facilities to meet the community’s electricity needs outside production time. Energy storage generally consists of batteries, with lead-acid batteries being the most common type. However, lithium-ion, nickel metal hydride, and sodium-ion batteries are generally more efficient and, as their costs continue to fall, their adoption is likely to rise. To avoid overcharging, the electricity produced is processed by charge controllers that regulate when batteries charge. Since solar panels generate direct current (DC) while most mainstream appliances require alternating current (AC), inverters are used to transform the electricity so that it can be used by households. Additionally, solar mini grids generally contain some remote monitoring. This allows the grid operator to collect data on usage and performance of the grid to better maintain and repair it. Finally, the distribution system connects the production site to households and businesses. It consists of distribution lines, transformers, and the infrastructure to support the lines (e.g., poles).

5 Step Initiative, 2014.
6 Ibid.
7 USAID, n.d.a.

Figure 1 Solar mini grid component[8]



In theory, solar panels have an expected lifetime of 20 to 30 years.[9] However, some components, such as batteries, need to be changed more frequently. Lead-acid batteries may need to be replaced every two to three years, inverters every five to ten years. **Table 1** details the life expectancy of the components. In practice, many parts may break down before their expected EoL. Poor quality, lack of maintenance, and overuse contribute to the premature wear of the system.

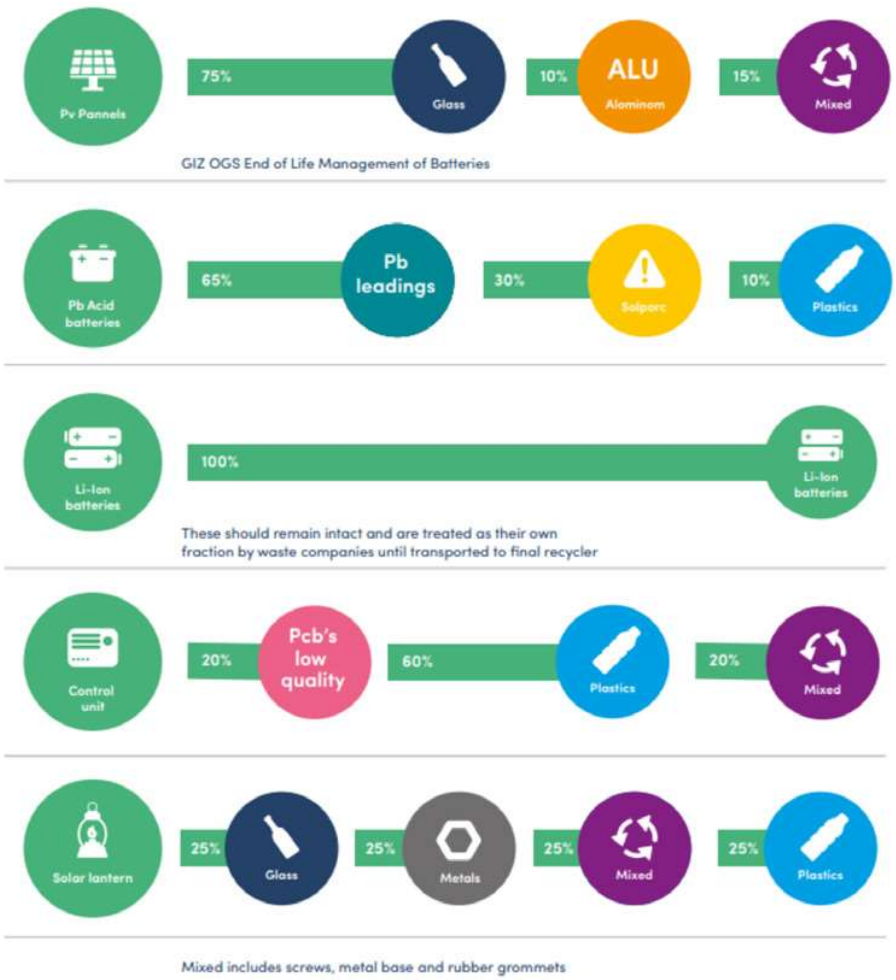
Table 1 Life expectancy of components of solar mini grids[10]

Component	Expected lifetimes	Typical material composition
PV panels	Over 10 years	Crystalline silicon, glass, aluminium, copper, trace elements (indium, tin, gallium, etc.)
Control devices	5-15 years	Printed circuit boards, solder paste, various electrical and electronic components, plastics
Batteries	2-6 years	Lead-acid batteries: lead, lead oxide, plastics, electrolytes (sulfuric acid). Lithium-ion batteries: graphite, various organic substances; copper, aluminium, lithium, plastics
Cables	Over 10 years	Copper, plastic insultation

Figure 2 outlines the material composition of different solar mini grid components, which has to be borne in mind for e-waste management.

8 Ibid.
9 IRENA, 2016b.
10 GIZ, 2018.

Figure 2 Composition of solar mini grid components[11]



2.2. How is e-waste disposed of currently?

As outlined in **Figure 2**, solar mini grids include many materials that require proper disposal, including plastics, lead, acid, cadmium, and nickel, with environmental and health risks associated with improper disposal of those materials. In fragile contexts, there is little infrastructure to safely discard e-waste. As a result, this task is generally left to the end-user. Given the lack of financial incentives to recycle the waste, e-waste eventually becomes hibernated (left in the house unused), burnt, buried, or dumped outside.[12] When there is an informal recycling sector, the valuable materials are stripped from the products and the rest is generally dumped in landfills. The informal recycling sector at Old Fadama scrap market in Ghana is an example of a highly organised informal recycling sector, and the challenges that it poses are outlined in **Box 1**.

11 GOGLA, 2022a, page 6.
12 Energypedia, n.d.a.

BOX 1 INFORMAL RECYCLING AT THE OLD FADAMA SCRAP MARKET IN ACCRA, GHANA[13]

Ghana faces a considerable e-waste challenge: growing EEE use and the import of second-hand EEE, many of which have short lifespans or are already broken on arrival, is putting pressure on the country's capacity to handle the surge of e-waste.

The Old Fadama scrap market, also known as Agbogbloshie, is located in the centre of Accra. It was the main site for the disposal and informal recycling of e-waste before its relocation in 2021. There were an estimated 1,500 dismantlers and between 4,000 and 5,000 collectors thought to be operating in the scrapyard, most of whom were under 25-years-old and with little formal education or training.

The scale of informal recycling was highly developed. Collectors collected or bought scraps from households. They then sold or delivered the scraps to scrap dealers. Once enough material had been accumulated, the EEE were then tested to see whether they still functioned. They were then dismantled and repurposed into new products. Once EEE was stripped of its valuable materials, the rest of the product was dumped into the scrapyard.

Recycling methods were very basic. Dismantling was done manually without the use of protective equipment. To extract copper, cables were predominantly burnt at low temperatures. This separates the plastic insulation from copper cables. The burnt plastic generated toxic fumes, endangering workers and nearby communities. Manual dismantling of lead-acid batteries was common.

Studies have found very high levels of metals, including cadmium, arsenic and lead, in the soil of the scrapyard, in levels higher than international environmental guidelines. This exposed nearby communities to toxins through ingestion or inhalation. High levels of pollutants were found in the blood, urine, and breast milk of scrapyard workers and members of nearby communities. This pollution led communities to be at higher risk of cancers, cardiovascular diseases, as well as breathing difficulties due to the open burning. Workers reported using higher levels of pain killers to deal with the symptoms.

Improper disposal creates significant environmental and health challenges. While the mini grid components are in use, the materials are not a threat since they are not exposed to outside elements. However, leaving the components in landfills, burning them, or roughly recycling them exposes the community to potentially toxic materials. **Table 2** lists the health and environmental risks of improper recycling methods. Informal recyclers are particularly at risk as they are in direct contact with hazardous materials. However, all nearby communities are affected: studies have found elevated levels of heavy metals and persistent organic pollutants in communities living near informal and formal recycling areas.[14]

13 Amoabeng Nti et al., 2021; Atiemo, S. et al., 2016; GIZ, 2022; Srigboh, R. et al., 2016.
14 Parvez, S. M. et al., 2021.

While all those materials should ideally be disposed of appropriately and recycled, some components pose a greater threat than others. Lead-acid batteries are particularly hazardous. When dismantled or damaged, they can leak lead and acid into the soil, polluting groundwater and endangering nearby communities. Lead is especially problematic since it is a heavy metal that is easily absorbed by organisms, it builds up over time, and it is difficult to remove from the environment. Children are particularly vulnerable to lead poisoning, which can cause severe neurological and development problems.[15] The toxicity of lead is so severe that World Health Organisation (WHO) has determined that there are no safe levels of exposure for children. In adults, it can cause high blood pressure and kidney damage. Lead also causes miscarriages and foetal defects in pregnant women.

Table 2 Risks presented with informal recycling[16]

Component	Risk	Materials	Risks when improperly recycled
Solar panels	Medium	Aluminium, glass, mixed plastics	Aluminium is stripped from the frame, which is then dumped.
Lead-acid batteries	High	Lead, acid, plastics	Risk of leakage of the lead-acid component if the battery shell is opened. The electrolytes within the battery are often drained, leading to lead contamination.
Lithium-ion batteries	High	Lithium-iron-phosphate or Lithium-manganese-oxide are the most common chemistry for solar products.	Risk of fire in storage due to thermal runaways.
Cables	Low	Copper and PVC (Polyvinyl Chloride, a plastic)	Informal recycling consists of burning the plastic to strip the copper of the PVC. Burnt PVC, which is a strong carcinogen, releases dioxins into the atmosphere.
Printed Circuit Boards (PCB)	Low	Gold, silver, other components	Informal recycling consists of burning or using acids to strip the gold from the board, which is very hazardous to workers and to the environment.

2.3. Recycling infrastructure and cost

Many of the components within a solar mini grid can be recycled. The better the quality of the recycling, the higher the fraction and quality of materials that can be extracted. The first difficulty with recycling solar mini grids components is that each are made of many different materials that need to be handled separately. **Table 3** covers the main components found in solar mini grids and where they can be recycled.

15 WHO, n.d.
16 GOGLA, 2022a.

Table 3 Recycling options for solar mini grid components[17]

Component	Recyclability	Geography
Glass	High – crushed and sold to glass manufacturers or given to cement manufacturers and lead smelters.	Local glass manufacturers, cement manufacturers, or lead smelters.
Mixed components	Low – depending on the quality of the components, they may sometimes be dismantled and segregated. If they cannot be dismantled, they are sent to a landfill.	Local landfills.
Lead-acid batteries	High – The battery is broken into pieces to separate the components. Lead plates are smelted, then lead ingots are created and sold to lead battery manufacturers. Acid is neutralised and turned into water before being released into the sewage system or recycled through innovative processes. Plastic pieces are washed and sent to a plastic recycler.	Kenya, India, China or other international facilities.
Plastics	Medium – Non-hazardous recyclable plastics are sorted by colour and sold to local plastic manufacturers. Non-recyclable, non-hazardous plastics are landfilled locally. Hazardous plastics, such as those containing flame retardants, should be incinerated at suitable facilities.	Recycling facilities, shipped internationally. Local landfills. Incineration facilities.
Lithium-ion batteries	Medium – There are few facilities that can recycle lithium-ion batteries. They are more complex than lead-acid batteries and require mechanical shredding to recycle. For now, the financial incentives are such that new metals needed for the manufacturing of batteries, such as cobalt, are cheaper than recycled metals. Unrecycled batteries are put into landfills.	Five recycling sites globally, located in the USA, Germany, and Belgium.
PCBs low quality	Low – PCBs are costly to recycle due to their complex design. They are classified by quality, with PCBs from off-grid solar products generally being of low quality: fewer precious metals (gold, silver) are found than in higher quality PCBs (e.g., in laptops). PCBs should be segregated from other components, the capacitors removed, and transported to international recyclers.	Europe and Middle East mainly.
Metals from cables	High - Copper found within cables is easy to recycle and very valuable. Cables are stripped of PVC and sold to local cable manufacturers.	Local recycling.
Metals from PV panels	High – aluminium from PV panels is valuable due to the high cost of new aluminium. E-waste operators generally sell aluminium to local metal scrapers who sell it on international markets.	Local recycling.
PV panels	Medium – The most complex part of a PV panel is separating the crystalline silicon wafers from the other components. Recycling starts with removing the aluminium frame, which, if done improperly, often shatters the glass and removes any possibility of separating out the materials. If that happens, the glass is sold to local cement industries but will contain traces of silver and other materials. More thorough recycling can separate out the glass from the silicon wafer, ensuring that a greater percentage of materials are recycled.	Locally for rudimentary recycling, Europe for more advanced recycling.

17 Ibid.

The second difficulty is that the proper disposal of e-waste requires building the infrastructure to manage waste. Setting up an infrastructure to recycle e-waste does not simply entail investing in expensive treatment facilities. It requires a whole network, including collection points, storage, and road networks. Recycling e-waste requires the following activities and infrastructure, illustrated also in **Figure 3**:[18]

- **Access to e-waste** – The first step is for the owner of the product to dispose of e-waste in an appropriate place where it can be collected and transported to treatment facilities. To ensure that individuals are aware that e-waste needs to be separated from other waste sources and that collection points exist, there is often a need to conduct awareness campaigns. Individuals may also require financial incentives before giving up used products. These can include discounts on new goods when consumers bring back old ones or direct payment for the waste when the recycled materials are profitable.

- **Collection points** – E-waste needs to be dropped off at collection points before it is collected and treated. Collection points should be set up close enough to consumers to make it easy for them to drop off used goods. This step is essential: without a dense network of collection points, recycling facilities are unable to collect enough material to cover the cost of recycling. Collection points can be set up in stores that sell EEE for example. Storage needs to be built to store the waste until large enough quantities have been collected before transporting the waste to dismantling facilities. This requires the proper management of storage, including the safe storage of batteries, the separation of components, and clear labels for containers.

- **Transport** – The next step is to transport e-waste from the collection points to the dismantling facilities. This includes all the logistics of transportation. Due to the hazardous nature of materials that are contained in batteries, transportation is often subject to national and international regulations and needs to follow safety guidelines. For example, lithium-ion batteries should be discharged using salt water, then stored in plastic containers filled with sand. The sand absorbs thermal runaways and avoids the spread of potential fires. Different national regulations define standards on how e-waste should be transported, including the proper labelling and types of vehicles used.

- **Treatment** – In the final step, e-waste is dismantled and recycled. This first involves dismantling the components into separate fractions. This can be done automatically or manually at quite low costs. The next step is to send different fractions to a recycling facility that will conduct a first recycling of the main materials. If they have positive value, the residual fractions can then be treated at specialised facilities to recover smaller amounts of materials. Both recycling steps are expensive as they entail complex recycling procedures. Many countries do not have recycling facilities, requiring them to send the dismantled goods to be treated abroad, which increases transportation costs.

18 GOGLA, 2022c.

Establishing an effective e-waste management infrastructure is expensive. The cost of recycling e-waste depends on the:

- **Types of components** – The value of a component depends on how easy it is to recycle – whether it is easily dismantlable, whether the processes to recover the materials are complex – and the value of the recycled materials. For example, lead-acid batteries generally have a positive recycling value. They are easy to dismantle, and lead can easily be recovered without losing its properties. Similarly, the copper content of cables determines whether recycling is profitable.

- **Quantities of e-waste** – Once large enough quantities of e-waste are generated, collected, and sent to treatment centres, recycling facilities can realise economies of scale. This implies that countries that have larger stocks of e-waste can recycle e-waste more profitably than countries with smaller amounts.

- **State of the current infrastructure** – The cost of building an e-waste management infrastructure decreases if there is already a base to be built on. This base can consist of existing solid waste management processes, or even an informal recycling sector. The cost also depends on the state of the road network: if the area is hard to reach with poor road connections, the cost of collecting e-waste increases.

Figure 3 E-waste recycling process[19]

19 Africa Clean Energy, 2019.

3. Challenges to e-waste management in fragile settings

Setting up proper e-waste disposal channels is a challenge that all countries are facing, including high-income countries. Challenges include the:

- **Lack of financial incentives** – Disposing of e-waste properly is generally too costly even when valuable raw materials can be extracted. The high cost involved in collecting used parts from remote areas and sending them to appropriate facilities where they can be recycled, together with the low volumes of e-waste involved, means that it is generally prohibitively costly to recycle e-waste. Without financial incentives to recycle waste, it is cheaper to dispose of waste improperly by leaving mini grids in disrepair or dumping or burning the equipment. The same applies for all types of EEE. This imposes a negative cost to whole communities.

- **Insufficient infrastructure** – Many countries lack solid waste management infrastructure, let alone facilities to recycle solar panels, circuit boards, and batteries. Collecting and storing waste in hard-to-reach areas is prohibitively costly. Once that waste is collected, it generally must be shipped to Asia or Europe for recycling.

- **Undeveloped regulations** – There is often limited legislation and regulations covering e-waste. Without government regulations, stakeholders are not given the legal responsibility to finance and undertake e-waste management. Only three countries (Ukraine, Cameroon, and Nigeria) out of the 39 countries categorised as fragile or conflict-affected have e-waste regulations. Regulations are hard to establish as there are several actors involved in the creation of the e-waste (the producers of each component of the solar mini grids, mini grid developers, and consumers). Even if regulations are adopted, they are often hard to enforce. Governments require capacity to set targets and monitor recycling chains.

- **Lack of awareness** – Consumers generally lack awareness on the environmental and health problems caused by e-waste.[20] This lack of awareness includes not just households, but also manufacturers and individuals working in waste management. A study in Hyderabad, India, found that 71% of handlers in solid waste centres were unaware of the health risks of e-waste.[21] Even when infrastructures are put in place, there is a lack of awareness on how to dispose of e-waste safely. This is a concern even in developed economies: in the UK, about 200 waste fires are due to the improper disposal of lithium-ion batteries each year.[22] There is also a lack of awareness of where to take back the e-waste, given that it falls outside of usual solid waste management channels.

20 GOGLA, 2022d.
21 Mishra, S. et al., 2017.
22 Fire Industry Association, 2023.

- **Poor maintenance and repair** – Solar mini grids require consistent maintenance and repair to ensure that they reach their expected lifespan. This includes cleaning the panels, avoiding overshading, and replacing used components, such as batteries and inverters. This is costly to do, especially in remote areas or conflict zones. Obtaining spare parts is expensive, with most parts needing to be imported. The local labour force often lacks the technical training to ensure the proper maintenance of the system. Additionally, EEE is generally not built with repair in mind: products are not easily dismantled, components are often not compatible with other brands, and components cannot easily be upgraded to remain relevant.[23]

- **Low quality and suitability of the solar mini grid** – Many solar panels break down before their expected EoL. Solar mini grids are sometimes built using cheap, ill-adapted, or second-hand components, leading to their premature EoL.[24] Matching demand to supply is also crucial in ensuring the sustainability of the mini grid. Low demand will not cover the cost of upkeep of the panels. Likewise, too high demand can lead to overloading, which will lead to the premature wear of the grid.

- **Inadequate data** – Many countries lack robust data on the quantity of e-waste in the country and its composition, in which geographic areas e-waste is concentrated, and where the e-waste ends up.[25] Lack of data makes it difficult for the government to design policies and regulations that effectively tackle the issue.

Compounding those issues, FCS face additional challenges:

- **Conflict and security issues** – Conflict and security issues make it difficult to maintain solar mini grids. It also makes collecting used parts of the mini grids more difficult.

- **Exchange rate fluctuations** – Volatile exchange rates and depreciation of local currency against hard currencies (e.g., the United States Dollar) can make it more expensive (in local currency terms) to import spare parts for repair. Foreign currency may also be difficult to source during times of macroeconomic instability, which is relatively common in FCS.

- **Poor governance** – FCS are characterised by limited government capacity, which can make it difficult for the government to develop and enforce e-waste regulations.

- **Resource constraints** – Governments in FCS are heavily resource-constrained, both in terms of human capital and financially, with limited capacity to increase revenue collection. It is challenging for governments of FCS to bear the financial responsibility for e-waste management.

23 GOGLA, 2022b.
24 Mehrotra, 2023.
25 Africa Clean Energy, 2019.

SOPA Images, Getty Images

Given the scale of the challenges, governments of FCS are unlikely to be able to develop strong recycling practices for all solar mini grid components and should instead be pragmatic. In collaboration with mini grid developers and international organisations, setting up effective e-waste management policies in this context would entail heavier reliance on prevention rather than disposal, with recycling efforts focused on the most hazardous components. In parallel, government can start developing regulations to ensure that private developers finance the establishment of recycling infrastructure.

4. Adopting circular economy principles

Often, waste management is focused only on processes that handle waste that is already generated. However, an effective e-waste management strategy requires a more holistic approach to waste: instead of only targeting waste once it is produced, it is better to consider the whole lifecycle of the product, from creation to disposal, and to minimise waste at each step of the way. This approach is based on circular economy principles. A circular economy is a "system in which all materials and components are kept at their highest value at all times, and waste is designed out of the system."[26] The Platform for Accelerating the Circular Economy (PACE) defines three objectives of a circular economy for electronics:[27]

1. New products are built using more recycled and recyclable content.
2. The lifecycle of the products and their components are extended for as long as possible.
3. Once a product or its components are no longer usable, they should be recycled to a high standard.

In practice, circularity implies that recycling should only be considered as a last resort. While recycling is useful to collect a fraction of the material, it is insufficient as the only e-waste management strategy. In many places, setting up recycling infrastructure for all e-waste products would be too costly to be realistic. This is particularly the case for FCS: once the waste is generated, governments may find it difficult to set up the required infrastructure to manage e-waste. Additionally, in most cases, recycling also entails a loss in the value of the materials as not all materials can be recuperated, and the material recycled often is of lower quality.

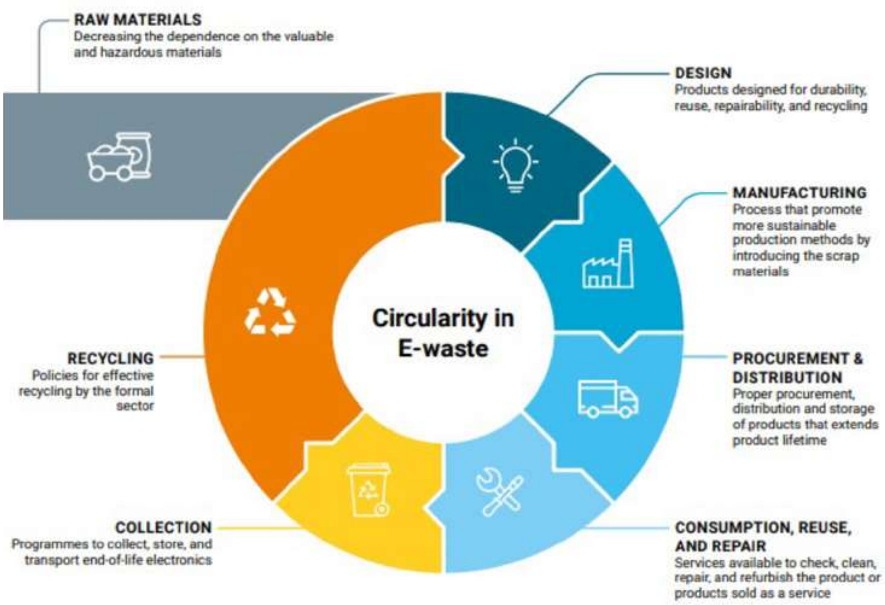
Instead, circularity emphasises design and repair to reduce e-waste. **Figure 4** illustrates the different steps of the lifecycle of a product. Products should be designed to be durable, easy to repair, and avoid incorporating toxic materials where possible. This effort from the manufacturers should be supported by procurement processes that emphasise durability and repairability. For example, procurement processes can include repairability standards. Once the mini grid is rolled out, it should then be supported by strong maintenance and repair strategies. By extending the lifecycle of solar mini grids as much as possible, this approach reduces the amount of e-waste in circulation. Only when the components can no longer be repaired should they be recycled to try and regain as much of the materials as possible. This raw material is then reintroduced in the production chain, so that as little unrecycled waste is left behind.

26 Platform for Accelerating the Circular Economy, 2021.
27 Ibid.

There can be tensions between recycling and prevention. Since there are economies of scale to recycling, it becomes more profitable as more waste is generated. From a recycler's point of view, it may be better to emphasise recyclability rather than durability or repairability. However, from a policymaker's perspective, it is essential to reduce all unnecessary waste to preserve resources and reduce the cost of treating e-waste. It is the responsibility of mini grid developers to ensure that the material installed is of high enough quality, maintained properly to ensure that the lifespan of the mini grid is as long as possible. Oversight from the government is required to ensure that those tensions are resolved in a way that maximises the welfare of communities.

The rest of the toolkit focuses on the application of circular economy principles at each step of solar mini grid's lifecyle. First, we will discuss how better design and planning can minimise e-waste. Then we will cover how repair and maintenance maximise the lifespan of the mini grid. Finally, we will focus on recycling strategies. The last section covers how government can regulate e-waste, including what financial models can be used.

Figure 4 Principles of circularity in e-waste[28]



28 GPA, 2022, page 9.

5. Preventing waste through careful design and implementation

This section argues that e-waste management should be a central part of the planning stages of mini grid installations rather than a separate issue. To avoid unnecessary waste, the mini grid needs to be well designed and adapted to the local environment. This requires careful planning by the developers before the mini grid is installed. Components should be chosen to maximise their durability and repairability. Information on demand is required to appropriately size the mini grid.

5.1. Installing the right components

When deciding on what solar mini grid components to install, producers should consider how the different components will be maintained, repaired, recycled, and disposed of.[29] Mini grid developers should consider the following characteristics when choosing components:

- **Durability of the components** – Components should be chosen to maximise their durability. This can be done by selecting higher quality materials that are resistant to wear and tear or by designing the product in a way that ensures it will be less affected by external elements. For example, lead-acid batteries have lower life expectancy in hot climates. Newer types of batteries can withstand higher temperatures.[30] Components must also be transported and stored adequately to ensure that they are functioning when they are installed. This is particularly the case for batteries, which can lose their capacities when stored improperly.[31]

- **Repairability of the components** – To ensure that the solar mini grids can easily be repaired, spare parts for each component should be easily obtainable in the local market. Repair of these components should be possible with standard tools. Components can be built to be interoperable: basic components, connectors, and fixings can be standardised across products and brands, which makes it more likely that the parts are available and that local repairers will have the knowledge and tools to repair the product. Good design also implies making sure that the product can be disassembled then reassembled by repair technicians.

- **Recyclability** – The components of solar panels should be built to ensure that as much of the raw materials as possible can be recycled and that the fractions recycled are of good quality.[32] This can take several forms, such as reducing the number of different plastics used in the product. Another example is ensuring that the different materials are separable (for example, by reducing the use of glue)

29 Developers can choose between different types of solar panels and batteries for example.
30 USAID, n.d.b.
31 GPA, 2022.
32 Higher quality fractions are fractions that have lower amounts of mixed materials.

so that they can enter different waste flows. The products should be designed such that it is easily recycled. For example, clear labels should be included within the product help to separate and recycle different materials.[33]

There may be some trade-offs between those different considerations. For example, more repairable products may not be as durable. Products that are more easily disassembled may be less likely to keep out the dust and rain. This can cause them to break down prematurely compared to products built more sturdily. However, both durability and repairability should be considered alongside one another when deciding which components to use.[34] **Box 2** outlines how these considerations can be considered together.

BOX 2 THE OFF GRID SOLAR SCORECARD35

There are many factors that can affect how repairable a product is. It is not easy for companies to choose between products and to weigh different factors of repairability. To address this issue, in 2015, Professor Jamie Cross along with a team of students in Kenya and India created an online tool that ranks solar lighting products. The Off Grid Solar Scorecard includes a set of indicators that quantifies how repairable a solar product is. It looks at the following characteristics:

- The ease of replacing or upgrading batteries.
- The quality of construction of the circuit board (soldered vs surface mounted) and the availability of replacements.
- Non-destructive disassembly and reassembly, which judges whether it is possible to disassemble a part of the product without damaging the rest.
- The use of glue welding, or non-reversible screws to assemble components.
- The tools required to disassemble and reassemble the product and how common they are among small-scale technicians.
- Time and complexity of disassembly.
- Access to information on disassembly or repair of a device.

Each manufacturer has a total of 100 points, with each category consisting of between five and 20 points. This Scorecard has gained traction among manufacturers and international organisations and, in 2017, the World Bank's Lighting Global programme cited the Scorecard as a minimum threshold for good designs.

33 GOGLA, 2022b.
34 Spear, R. et al., 2020.
35 Hoyes Flight, M., 2022.

Mini grids developers therefore need to make informed decisions when selecting what components are to be used for mini grids. Better quality mini grids implies both more durable components but also components that are easier to repair or recycle. Both approaches reduce the amount of e-waste produced and increase the probability that the components will be effectively treated. Policymakers can define minimum quality standards to ensure that the mini grids will last beyond a few years.

5.2. Getting the demand right through careful planning

Ensuring that the demand for energy matches supply is key to ensure that the solar mini grid is managed sustainably. If demand is too low, then the fixed maintenance cost is unlikely to be met by existing clients. Given the low income of electricity consumers in hard-to-reach areas and FCS, companies cannot cover this maintenance cost by raising electricity prices. Without the adequate funds to repair the grid, they may have to leave the solar mini grid in disrepair. Likewise, if energy demand is too high, the mini grid will be overloaded and age prematurely. A research paper found that on five out of six sites in Nigeria, the solar mini grids were undersized compared to the current or expected load.[36] Similarly, a case study of solar mini grids in rural Kenya show that the mini grid was unable to meet increases in energy demand, leading to power outages.[37] This, in turn, led to dissatisfaction from consumers, which affected their willingness to pay for the services, thereby deteriorating the long-term prospects of the solar mini grid.

To ensure that the demand for electricity is sufficiently high, there should be assessments of existing or potential economic activities and consultations with communities ahead of the installation to ensure community buy-in. Ensuring the quality of the electricity provision helps build trust within the communities and boost uptake. To avoid overloading, the size of the mini grid should also be carefully thought through. Additional or larger batteries may be required to avoid deep discharges, especially for lead-acid batteries.[38] Policies that enhance productive use of energy would also increase the use of electricity and data needs to be collected to assess current and future electricity needs.

Three toolkits in this series, *Demand-side factors: Tools to measure, incentivise, and sustain demand for solar mini grids in fragile contexts; Driving productive use of energy in fragile contexts;* and *Data and technology: Challenges and opportunities for solar mini grids in fragile contexts* can help stakeholders ensure that there is enough demand to meet the cost of maintenance of the mini grid. Similarly, before the solar mini grid is rolled out, proper planning needs to occur to ensure that the national electricity grid will not be rolled out to the same area, rendering the solar mini grid obsolete. Policymakers and developers can refer to the toolkit *Legal and regulatory framework: Facilitating an enabling environment for solar mini grids in fragile contexts* to obtain advice on how to prepare for the rollout of the national grid.

36 Ugwu, et al., 2022.
37 Boliko & Ialnazov, 2019.
38 USAID, n.d.b.

Guy Peterson,
Getty Images

This section showed that a large component of reducing e-waste is to be done before mini grid construction, through better design and planning. Components that are designed to be durable and repairable will be less costly to replace down the line. The use of data is key to ensure that demand, both current and future, is accurately captured, ensuring that the mini grid meets the needs of the community it serves. Once the grid is installed, the next step is to ensure proper maintenance and repair.

6. Maintenance and repair

It is important to ensure that the components of the mini grids last as long as possible through proper maintenance and repair. In theory, solar mini grids can last up to 20-30 years. However, several components of the mini grid, such as the batteries and the inverters, need to be replaced at an earlier date compared to solar panels. **Table 1** earlier presents the expected lifetimes of the components of solar mini grids. In practice, the lifespan of different components will be affected by different factors: the environment, including the temperature which affects batteries, proper monitoring and maintenance of the mini grid, and the use of the mini grid, including avoiding overloading the system.

Operations and maintenance (O&M) activities are essential to the good functioning of the grid. These activities refer to all activities carried out once the mini grid has been commissioned. **Table 4** describes all maintenance activities. Depending on the ownership structure of the mini grid, O&M activities can be performed by the developer or handed over to a contractor or the community that the mini grid serves. Hybrid-systems such as public-private partnerships (PPPs) can share responsibilities between government and private developers.

Table 4 Operation and maintenance activities[39]

Type	Definition	Activities
Preventative maintenance	This includes routine inspection and servicing of equipment to reduce interruptions in the power supply. The frequency of these activities is determined by the technology used, the local environment of the site, the seasonal variation in climate, and the manufacturer's recommendations.	• Solar panel cleaning • Vegetation management to avoid shading the panels • DC and AC electrical systems cleaning • Checking the integrity of connections and terminations • Electrical tests for solar panels, inverters, and batteries • Mechanical inspections • Documentation • Physical observations • Thermographic imaging to identify potential failure-prone modules or components
Reactive maintenance	Technicians are sent to repair faulty equipment after a failure in the power supply. Response time should be determined by minimising the down time of the system while considering the cost of sending a technician quickly to repair the system.	• Failure analysis • Emergency maintenance • Repairs and replacements • Replacement of fuses and meters • Rectifying SCADA/remote monitoring systems faults • Rectifying tracking systems
Condition-based maintenance	Monitoring the condition of the equipment on a real-time basis, to spot and address potential problems early. This requires remote monitoring systems installed.	• Analysis of real time monitoring data • Intervention when underperformance detected

39 African Development Bank, 2020.

There are several benefits to preventative maintenance and repair:

- **Environmental** – It allows energy and materials savings by avoiding premature replacement of the components. It also minimises the amount of e-waste generated by ensuring that existing components are used as long as possible.
- **Economic** – Local communities have an important role to play in ensuring that the solar mini grid is properly maintained and repaired. These services in turn create local employment opportunities, can help build skills, and foster a sense of ownership of the mini grid in the community.
- **Costs** – When using local services, the transportation cost incurred to repair or replace damaged components is reduced. Regular and preventative maintenance reduces the frequency of reactive maintenance, decreasing the associated cost.
- **Social** – Preventative maintenance and repair increase the reliability of the mini grid, which increases the trust the community has in the mini grid. A worry is that communities may reject the mini grid, as they may perceive it as less desirable than the national grid. They may also be reluctant to invest in EEE when the mini grid is perceived as unreliable. This creates a negative feedback loop, with low trust generating low demand, which then makes maintenance less economically viable, which further reduces the reliability of the grid. It is essential to counter this dynamic by strengthening community trust in the mini grid.

Despite its benefits, processes to conduct repair and maintenance are hard to set up. This is due to:

- **High financial cost** – Sending technicians to conduct maintenance or repairs is costly in remote areas. In conflict-affected areas, maintenance operations may have to be put on hold until security improves.
- **Lack of economies of scale** – Unless the operator has several mini grids operating close to one another, the cost of maintenance is likely to be high since technicians cannot be sent to conduct routine maintenance inspections on several grids at the same time.
- **Lack of spare parts and tools** – Spare parts and tools for repairers are generally lacking. This is because most EEE are not produced locally but are imported, which can be costly due to tariffs, exchange rate fluctuations, and scarcity of foreign currency. They are also costly to transport to remote rural areas. Finally, components of EEE are seldom interchangeable. When a product breaks, several of its components could still be functional and used to repair other EEE products. However, in practice, a lot of the components are brand- or product-specific, which means they do not fit other products. The same is true for tools: EEE products may require brand-specific tools for repair and dismantling.

Developers can develop different solutions to these challenges, including:

- **Providing training to local technicians** – To ensure the proper maintenance and repair of the solar mini grid, the operator should provide training to local technicians. Local operators can conduct more frequent preventative maintenance activities and be the first to intervene in cases of troubleshooting. Technical staff can be sent locally from a central hub for more complex maintenance activities. Operators should provide regular training to local technicians to ensure the proper maintenance of the grid, including on most common maintenance tasks and their frequency, as well as basic repair practices.

- **Ensuring that the cost of O&M activities is appropriately budgeted** – The cost of these activities needs to be properly reflected in the tariff to ensure that there are resources for them to be carried out. Operators need to strike a balance between mini grid reliability and affordability for the community. The cost of O&M activities is often underestimated, which leads to solar mini grids being abandoned after a couple of years. They are then sometimes left in the field instead of collected and disposed of.[40] Operators should be clear on which O&M activities are essential to ensure that this does not happen and to frequently update cost estimates to ensure that they are adequately priced in.

- **Ensuring that spare parts and tools are available to local technicians** – The mini grid developer should ensure that spare parts and tools are easily available in the local area. The company needs to have data on what are the components that break the most easily to ensure that they are supplied to the local area. The design of the grid should include as many commonly used spare parts as possible. Most spare parts are likely to be imported. Mini grid developers should consider the cost of importing those parts, including import duties and risks of exchange rate fluctuations, when budgeting their maintenance costs.

- **Adopting technological solutions to facilitate repair** – Companies can develop mechanisms that make it easier for technicians to maintain and repair the solar mini grid. For example, SolarAid, a solar lantern company, has developed a repair app to help its technicians repair broken solar lanterns. It contains videos on how to conduct the repair for the most common faults. Additionally, using smart products, such as remote troubleshooting abilities, can vastly improve the producer's ability to identify potential failures in the system. The electricity provider can then know in real time which parts and tools to send to the area, reducing the number of trips needed to assess and solve the problem. [41] An example of remote monitoring is included in **Box 3.**

40 Mehrotra, 2023.
41 Energypedia, n.d.b.

BOX 3 USING REMOTE MONITORING TO LOWER MAINTENANCE COST IN TANZANIA[42]

To lower the cost of maintenance of eight mini grids in rural Tanzania, remote monitoring solutions were adopted. Two types of monitoring were used:

- **Basic monitoring** – this includes remote access to basic operational system parameters, including the operational state, the overall output power, PV generation, battery voltage, and temperature.
- **Advanced monitoring** – this includes more advanced monitoring solutions, including the collection of data on a greater number of parameters, the integration of data across multiple vendors and assets, advanced data analytics to provide better insights, alerts to operators, and remote control and configurations.

Examples of how this monitoring was used:

- **Ensuring the proper use of the batteries** – basic monitoring provides information on the temperature of the battery. When it was found to be above the expected range, it triggered an in-person investigation. This led to the installation of a shading structure to block direct sunlight on the container wall, which reduced the temperature from 29°C to 25°C, extending the battery lifetime. More advanced monitoring can reduce the depths of discharge.
- **Avoiding unnecessary trips** – gathering as much data remotely ensures that no unnecessary trips are carried out to remote locations. Instead, on-site labour can be used for urgent, non-complex technical problems.

42 AMMP Technologies, 2018.

7. Recycling and disposal

In the final stage of the lifecycle of the solar mini grids, systems should be put in place to recycle as much of the materials as possible from the solar mini grid components. These systems are costly. Existing waste collection is likely to be very limited. This is especially true in hard-to-reach remote areas. The following section offers advice on how to set up recycling infrastructure, as well as how to leverage the informal sector.

7.1. Recycling infrastructure

As described above, setting up an efficient recycling infrastructure requires setting up a dense network of collection points, along with storage and transportation systems, before sending the used components to dismantling facilities. Separated components are then generally sent abroad to be recycled.

The necessary infrastructure is likely to be limited in FCS, especially in the more remote areas that solar mini grid developers are planning to reach. In most countries, including high income countries, this infrastructure is still being set up. However, there are still avenues to ensure that the most hazardous components of the solar mini grid are recycled:

- **Collaborate with other EEE sellers to set up e-waste collection points** – It is cheaper to collect many batteries before transporting them rather than a few at a time. It is unlikely that a single developer has enough solar mini grids in an area to cover the cost of transportation to treatment facilities. However, developers can collaborate with other EEE sellers to set up collection points for common e-waste components, such as cables and batteries. While lead-acid batteries contain the most hazardous material, they are also widely recycled. By pooling all e-waste categories together, developers can reduce the cost of transporting e-waste to the appropriate facilities.

- **Survey e-waste recyclers available in the country** – While a full infrastructure network might not be fully developed, there may be dismantling facilities that are available within the country. This is especially the case for most common types of EEE products, such as cables and batteries. Solar panels may also be recycled crudely within the country if treated as glass. Developers should survey the waste facilities in their country of operation and in surrounding areas to develop an e-waste management plan.

- **Plan for the treatment of the most hazardous fractions** – Even in the absence of facilities, developers should have a contingency plan for the safe disposal of batteries. Lead-acid batteries, for which the risk to local communities is high, require particular care. This requires budgeting the cost of take-back and transportation to safe disposal facilities, either locally or abroad. To lower transportation cost, take-backs of EEE can be scheduled to align with routine maintenance operations.

- **Collaborate with other EEE sellers and government to develop the infrastructure in the long term** – Over time, and as more e-waste is introduced within the country, developers should collaborate with governments and other EEE sellers to develop the infrastructure to better recycle and dispose of the e-waste generated by panels, batteries, cables, PCBs, and other types of EEE. This includes supporting the development of regulations and policies for the safe disposal of e-waste. This is covered in more detail in section 8.

7.2. Engaging the informal sector

The informal sector plays a key role in e-waste management. In many countries, there is an informal sector that partially recycles e-waste. As mentioned in previous sections, it focuses on easily recyclable materials: lead-acid batteries, extracting copper from cables or gold from PCBs. This is generally done with little protection for the health of workers or nearby residents or safeguards for the environment. The informal sector can also be in competition with the formal recycling sector when it exists: because the informal sector only uses the valuable recyclable sections of EEE, it can recycle products more cheaply than formal recyclers can. It can then offer higher compensation to e-waste sellers (households, businesses, etc.) and reduce the amount of e-waste formal recyclers have access to.

However, instead of considering the informal sector as a competitor, the government and EEE manufacturers can see it as an opportunity. Informal recyclers generally have a well-developed collection network that governments can build on. It is a cheaper way of bringing more e-waste into the formal disposal process. Additionally, informal recycling represents an important livelihood for many people. Governments need to ensure that informal recyclers are taken into consideration when designing recycling systems so that these systems do not foster tensions within local communities.

To improve the conditions of recycling, the government can actively engage the informal sector by:

- **Developing standards for recycling** – Policymakers should set standards on safe recycling procedures, including the methods, protection, and the safe disposal of left-over materials. These standards should clearly explain what EEE is covered and what methodologies are preferred. They should then be explicitly conveyed to the informal sector. Section 8 reviews these standards in greater detail.

- **Establishing collection centres or drop-off points** – Recyclers should be incentivised to drop of e-waste collected at safe collection centres. These should have the adequate facilities to store e-waste before it can be transported to recycling facilities.

- **Providing financial incentives** – Governments or formal recyclers can provide financial incentives to informal recyclers to collect EEE and drop them off at established collection points. Recycling can then be handled by formal recyclers. For example, Ghana set up an incentive system in 2017 where informal recyclers were offered a price per tonne of cable that they bring back. This made use of the informal sector collection network rather than setting up a new parallel system.[43]

- **Distributing personal protective equipment (PPE)** – To ensure that workers are protected, governments and private companies can distribute common PPE to informal workers. Basic equipment includes chemical resistant gloves, safety glasses, coveralls, and work boots.[44]

- **Providing training** – Providing training to informal workers on how to safely handle e-waste can improve the quality of the recycling and better protect workers. For example, training can teach workers to wear their PPE, to change clothes after work, methods to dismantle batteries without damaging them, and maintaining high personal hygiene standards to avoid contamination.

- **Conducting awareness campaigns** – Campaigns that raise awareness of the risks of improper dismantling and recycling of e-waste to informal workers' health and to the environment can be conducted alongside training programmes.

43 Bimpong et al., 2023; GIZ, 2020.
44 GOGLA, 2022a.

8. Regulating e-waste

As mentioned in section 1, the cost of safely disposing of e-waste generally outweighs the retail value of recovered components, providing little financial incentive to conduct anything more than very basic recycling of panels, cables, and batteries. Without government interventions, any effort to dispose of e-waste properly is likely to be limited to a few initiatives. To scale up any effort requires government to regulate the sector.

This section highlights potential pathways for governments to fund recycling infrastructure. It also introduces the most common e-waste legislation, Extended Producer Responsibility (EPR). Finally, it proposes ways for governments to monitor and enforce regulations.

8.1. The role of e-waste regulation

E-waste regulations determine the standards with which e-waste should be collected, transported, and recycled. These regulations also determine which products should be covered by the regulations, depending on how harmful the products are. To ensure that the regulations are applied and enforced, they need to be supported by policies that determine who oversees financing e-waste management and how this is done, as well as who is responsible for e-waste management operations.

Most FCS are already part of international conventions that restrict the flow of e-waste between countries. The Basel Convention, signed in 1989 and effective since 1992, restricts the movement of hazardous waste between countries, especially from high-income countries to low-income economies. As of June 2024, it has been signed by 191 parties. The Stockholm Convention, effective since 2004, restricts the production and use of persistent organic pollutants (POP). The Bamako Convention, effective since 1998, prohibits the import of hazardous waste into African countries and restricts the transboundary movement of hazardous waste between African countries. However, to properly tackle the challenges of e-waste within their own borders, governments need to supplement these international agreements with national regulations and policies.

In doing so, governments face several difficulties:

- **Lack of data on e-waste stocks** – Many countries lack data on how much e-waste is produced in the economy, where it is located, what its composition is, and how it is currently handled. Regulation development is hindered by a lack of knowledge on the scale of the issue.

- **Difficulties in collaborating with many stakeholders** – E-waste management includes several stakeholders, such as households, EEE sellers, solar mini grid developers, importers, and businesses. On the part of government, it requires collaboration between many different departments: for example, the Ministry of the Environment generally oversees the standards of e-waste disposal, the Bureau of Statistics oversees data collection, while municipal governments may be responsible for setting up collection points or organising awareness campaigns. Governments need to ensure that each stakeholder collaborates, and that the regulations clearly assign responsibilities to each group.

- **Lack of capacity within governments** – Governments of FCS tend to have limited capacity. They generally lack the funding and human resources needed to undertake development of and oversee implementation of e-waste regulations. To develop and effectively implement e-waste regulations will require them to collaborate with the international community and other countries.

- **Lack of interest** – For many FCS facing a wide range of challenges, e-waste management is often not a priority. Regardless, mini grid developers can still implement voluntary e-waste management schemes at a small scale. Interest in e-waste management generally grows as the market penetration of EEE increases, which explains why many countries are currently developing e-waste regulations. However, unless there is interest from policymakers, countries are unlikely to prioritise this.

Only three out of 39 countries on the World Bank's list of FCS countries have national e-waste regulations: Cameroon, Nigeria, and Ukraine.[45] FCS includes a wide range of countries with very different situations, with some countries having more capacity to develop and implement e-waste regulations than others. Nigeria is an example of a country that embarked on developing e-waste regulations when e-waste stocks became significant.

8.2. Extended Producer Responsibility (EPR)

Once standards are put into law, governments need to set up policy instruments that put those standards into action. This includes establishing responsibility between different stakeholders. The most common form of e-waste policy is the Extended Producer Responsibility (EPR).[46] EPR is a policy approach that makes producers responsible for the products they produce even after they have reached their EoL. Holding the producer responsible rather than the consumer has the advantage of ensuring that the producer has an incentive to design and maintain the EEE in such a way as to maximise the length of its lifespan and to reduce e-waste.[47]

45 UNITAR, 2024.
46 Energypedia, 2022.
47 Eucolight, n.d.

Within EPRs, different responsibilities can be assigned to producers. In financial EPRs, producers are responsible only for financing the cost of operations of e-waste management. Undertaking and managing e-waste management operations themselves, including collection and treatment, is left to public sector authorities. The fee should cover the full cost of managing e-waste, including collection, disposal, awareness campaigns, and training. In operational EPRs, the producers are responsible for setting up collection of e-waste as well as covering the cost. In those instances, the public sector's role is limited to setting standards, targets, and to monitoring e-waste collection.

Producers can meet their obligations either individually or collectively. More commonly, producers come together to form a Producer Responsibility Organisation (PRO). PROs are intermediaries that are paid by producers to ensure that the producers comply with existing e-waste regulations and policies. The PRO oversees the operational management of e-waste on behalf of producers. These PROs can be either for-profit or non-profit. They are generally governed by producers themselves, forming a separate legal entity whose role is to manage e-waste. Producers pay a fee to the PRO to cover the cost of their activities.

EPRs can be voluntary or mandatory. Voluntary schemes are driven by business initiatives. Since they require no new regulations and no monitoring, they are less costly for governments to manage; however, given the cost of managing e-waste, they are likely to be limited in scope and quantity. Voluntary schemes are generally used for materials that are already profitable to recycle, which is unlikely to apply to solar mini grids in fragile contexts. One way forward is for donors and investors to push mini grid developers to have an e-waste management strategy, accompanied by monitoring and evaluating the effectiveness of developers' e-waste management. For now, this is not generally included in their requirements. In most cases, governments will have to regulate e-waste to ensure that producers do recycle.

Integral to a successful EPR policy is to:

- **Define the products covered by the regulation** – The regulation should be clear on which products are covered by the EPR and which are not. This includes defining whether all solar panels are included or only some types, whether it includes cables and inverters, and the types of batteries included.

- **Define who the producer is** – The regulation should be clear on who the producer is. In the context of solar mini grids, this means determining whether it is the mini grid developer or operator, the producer of the components, or the importer who is legally responsible. The most common definition is the company that places the product on the market – i.e., the manufacturer, importer, or the brand owner of the product.[48]

48 Africa Clean Energy, 2019.

- **Define targets** – By setting clear targets, the government can influence the behaviour of producers and recyclers. These targets need to be set in consultation with stakeholders, considering the cost and the benefit of meeting those targets. They should be ambitious but achievable. They can be periodically adjusted in consultation with all stakeholders involved as capacity improves. Targets can be based on either collection or recycling rates.

- **Set up mechanisms for dialogue between stakeholders** – To set up the policy and to reduce conflict even after it is in place, EPR systems can put in place specific dialogue mechanisms. Key stakeholders need to be included to attain genuine and transparent collaboration. **Table 5** reviews all stakeholders and the roles that they generally hold.

- **Ensure that the EPR is financially viable** – The EPR needs to be set up in such a way that it is financially viable. The fees to PROs, for example, should be calculated to cover the collection, transportation, treatment and disposal, auditing, awareness campaigns, and the overall management of the fee. Fees can be variable, based on the type of product or volume, or fixed annually. The different financial mechanisms are covered in the next section.

Table 5 Key stakeholders in the e-waste management chain and their roles

Stakeholders	Roles
National government	• Define responsibilities between different stakeholders • Set up financing mechanisms • Set standards for e-waste management • Enforce regulations • Provide trainings and conduct awareness campaigns • Collect data on e-waste • Register companies importing e-waste
Local government	• Ensure that local areas have the infrastructure needed to collect e-waste
International donors	• Set up requirements for solar mini grids developers to have an e-waste management strategy • Monitor and evaluate the effectiveness of e-waste strategies • Help governments in setting up legislations
Mini grid distributors	• Ensure that the solar mini grid is composed of elements that are durable, repairable, and recyclable • Maintain and repair the solar mini grid
Households	• Take back broken appliances to be repaired • Take back appliances that can no longer be repaired to collection points
Importers	• Register electronic appliances imported into the country with the relevant authorities • Pay fee to PROs
Retailers	• Ensure that spare parts are available for repair • Set up collection points for appliances
Formal recyclers	• Register with the relevant authorities • Ensure that the recycling process meets the environmental and social standards set by governments
Informal recyclers	• Participate in EPR talks • Receive training • Collect waste and offer basic recycling

An example of a country developing its e-waste regulations is included in **Box 4** below.

BOX 4 RWANDA'S 2018 LAW ON E-WASTE REGULATION[49]

In 2018, Rwanda revised its Organic Law of 2005 to recognise e-waste as hazardous. The law stipulates that it should be collected and treated in a way that does not damage the environment or human health. Solar products are included as electric equipment.

The government is currently drafting an EPR, with producers being legally required to finance and organise the management of e-waste. Producers are defined as "[a]ny person or entity who introduces or causes to be introduced new and used electrical and electronic equipment into the market by sale, donation, gifts, inheritance or by any such related methods and can either be a manufacturer, importer, distributor or assembler."

In addition, under the draft law, any entity involved in waste management activities needs to have a licence from the Rwanda Utilities Regulatory Authority (RURA). Similarly, any producer or importer of EEE must have authorisation and proof of payment of a licence fee.

Despite its considerable regulatory effort, there are still gaps in its current regulation, including:

- **Establishing clear responsibilities:** Rwanda is yet to establish practical guidelines that clearly establishes the role and responsibilities of different stakeholders along the e-waste management chain.
- **Avoiding overlap between agencies:** The Ministry of Trade and Industry initiated a lot of the e-waste management agenda, through the construction of an e-waste facility and the publication of the Sanitation Policy. However, enforcement has been left to both the Rwanda Environmental Management Authority (REMA) and RURA. Both agencies have also been in charge of raising awareness.
- **Lack of mandatory e-waste management plans:** Solar companies are not required to have an environmental management plan (EMP) to facilitate the management of the products once they reach their EoL. Even government programmes, such as the subsidies scheme to increase the distribution of solar panels, have no EMP requirements.

49 Rwanda Green Fund, 2018.

8.3. Financing e-waste management

Beyond the cost of collecting, storing, and recycling e-waste, governments need additional revenue to monitor and enforce the proper management of e-waste. This includes making sure that producers are respecting existing national and international regulations, ensuring the quality of recycling centres in the country, conducting research into the safe disposal of e-waste, writing guidelines, raising awareness among the public, and providing training.

Governments in FCS already face severe resource constraints and are unlikely to be able to finance the development of a recycling infrastructure without leveraging funds from other sources, including external assistance. There are several financial models that countries around the world have adopted to finance their e-waste management. Some of these examples include:

- **Waste-holder financing** – The individual that disposes of the waste pays. This is generally what happens when government does not regulate e-waste. The last person to own the product when it breaks is the one who would have to pay to dispose of the waste safely. In practice, waste-holders are rarely willing to pay, opting instead to keep the product at home or dump it illegally.
- **Advanced recycling fee** – Consumers are charged a fee when they buy electronic products. This fee is then held by government to invest in the e-waste management system. This is unlikely to be a feasible option in FCS, where purchasing power is low and imposing additional fees on consumers is likely to make purchase of EEE more difficult. In Switzerland, consumers pay an advance recycling fee that covers the whole cost of recycling.
- **Taxation** – The government or an authorised body collects a tax on EEE products. In this system, consumers or producers pay a tax to government that covers the cost of e-waste management. However, many FCS have limited capacity to collect taxes, making it an unlikely option.
- **Producer financing** – The original manufacturer or importer pays a fee to government that covers the partial or total cost of recycling e-waste. This can either be enforced when the product is introduced in the market (such as Ghana's eco-tax) or when the product reaches its EoL (such as compliance fees).

When deciding which financing system to use, governments need to determine their own capacity to collect payment and consumers' or producers' ability to pay. The government also needs to consider who bears the incidence of the fee or tax: while producers may be responsible for paying the eco-tax to government, producers can pass the cost on to customers by raising the final prices of the products or electricity, thereby reducing affordability of EEE.

Examples of how Ghana and Rwanda have approached e-waste regulations are outlined in **Box 5** and **Box 6**, respectively.

BOX 5 GHANA'S 'ECO-TAX' ON ELECTRIC AND ELECTRONIC EQUIPMENT[50]

Ghana faces a significant e-waste challenge, with developed countries exporting their e-waste to Ghana. The Agbogbloshie dumpsite in Accra is the largest e-waste dumpsite in Africa, with an estimated 250,000 tonnes of electrical and electronic waste dumped annually.

In 2016, Ghana adopted the Hazardous and Electronic Waste Control Act. This EPR policy requires all EEE producers to register with the Environmental Protection Agency (EPA) and pay an "eco levy" to the Ghana Revenue Authority. This levy is then allocated to a fund managed by the EPA that manages the treatment of e-waste. Producers are either importers or manufacturers in Ghana. Rates of the eco levy vary by type of product. For example, cellular telephones have a USD 1 levy while refrigerators face a USD 5 levy. Any company that fails to register with the EPA or to pay the eco levy faces a fine up to twice the amount of the eco levy.

The fund then uses the revenue raised to build recycling infrastructure, produce research into electronic waste treatment and recycling, conduct awareness campaigns, produce guidelines for safe management of e-waste, and for monitoring and evaluation.

While the law has passed, Ghana's government is still in the process of setting up processes to implement it. This includes defining the roles of different stakeholders within the e-waste value chain.

BOX 6 RWANDA'S DEVELOPING E-WASTE INFRASTRUCTURE: PUBLIC-PRIVATE PARTNERSHIP WITH ENVIROSERVE[51]

The Ministry of Trade and Industry (MINICOM) in Rwanda launched a competitive tender to establish and manage a state-of-the-art e-waste dismantling facility. The winner of the contract is Enviroserve Dubai, a company with 15 years of experience in e-waste management. In January 2018, the Government of Rwanda entered into a public-private partnership with Enviroserve for the establishment and management of an e-waste facility. The facility was built in Gashora by MINICOM using funding of over USD 1.5 million from the Rwanda Green Fund.

50 MESTI, 2019.
51 Rwanda Green Fund, 2018; Africa Clean Energy, 2021.

The role of Enviroserve is to:

- Operate and manage the facility.
- Develop e-waste collection points in the country.
- Invest in new equipment and machinery to expand the facility, such as refrigerant gas recycling.
- Conduct public awareness campaigns about the proper management of e-waste and the health and environmental impact of improperly disposing of e-waste.

The PPP deal has the following characteristics:

- **Ownership of the facility:** The facility is owned by MINCOM but is run by Enviroserve through a 10-year renewable lease. Enviroserve pays a lease fee to the government. This revenue is then reinvested in environmental and green initiatives through the Rwanda Green Fund.
- **Revenue sharing:** Revenue from recycling is generated from selling recoverable materials, refurbished items, and repurposed batteries. Enviroserve and the government share the revenues.
- **Performance criteria:** The government has set targets that Enviroserve needs to meet. It needs to have undertaken and certified the facility's environmental impact assessment study. The government has the responsibility to monitor the environmental performance compliance of the facility.

Enviroserve still faces difficulties, including:

- **Collection infrastructure:** Enviroserve has not yet met its target of establishing 30 collection points in the country and does not have enough collection trucks to service all of its collection points.
- **Cost of e-waste disposal:** Solar companies find it difficult to meet the cost of disposing of their solar e-waste with Enviroserve.
- **Suboptimal utilisation of the recycling plant:** The facility is not operating at capacity because not all of the e-waste generated in Rwanda ends up at the facility. Low public awareness and take-back rates are partly to blame. Additionally, the facility cannot yet process lithium-ion batteries.

8.4. Enforcing regulations

Once the regulation is adopted, government needs to set up a system to ensure that it is enforced. This is likely to be a challenge in FCS, as government resources and capacity are already strained. Enforcing regulation generally requires collaboration across multiple ministries and government agencies. To ensure that producers respect the law, government will need to:[52]

52 ITU, 2021.

- **Define clear penalties for non-compliance** – To deter non-compliance, the government should impose fines on companies that are not respecting the regulation. However, care is needed when setting the value of the fine: low fines may not be effective in deterring non-compliance, but too high a fine may force firms to close, especially smaller businesses. Fines can be increased gradually, with a system of warnings for small breaches of the regulations and more flagrant non-compliance can be met with more severe fines as well as cancellation of licences.

- **Monitor waste management companies** – To ensure that waste management companies meet their targets, governments should set up monitoring systems, including scheduling regular audits. For this purpose, all waste management companies should be registered and keep records of their inputs and outputs.[53]

- **Assign clear responsibility across ministries** – One public body should be given the responsibility to oversee the implementation of e-waste regulations.

- **Foster collaboration between government entities** – Different government agencies need to coordinate their efforts to ensure effective monitoring of e-waste regulations. E-waste management is generally overseen by the Ministry of the Environment, while data is compiled by the Bureau of Statistics.

- **Build capacity within ministries** – Capacity within ministries should be built by ensuring they are adequately staffed and that their employees are regularly trained. At the minimum, governments are required to provide oversight and enforce the EPR and ensure that the environmental and social standards are adhered to. Given resource constraints in FCS, a potential way forward is to implement the EPR gradually, first ensuring compliance with the EPR scheme before setting targets.

- **Develop local enforcement capacity** – Local government can play a key role in implementing e-waste regulations. E-waste generally falls outside of local government's remit since it is not household waste; however, local governments oversee implementing national law at the local level.

- **Collect data** – Data on e-waste volumes and recycling goals are essential to help the government plan. Government should create processes to collect and analyse data to continuously monitor and enforce e-waste management.[54] Relevant data points include the volume of e-waste, the number of imported electronics, and tonnes of e-waste recycled. UNITAR and the International Telecommunication Union (ITU) have developed international standards on how governments can collect data on e-waste, which is generally based on the amount of imported EEE. These organisations also provide training to governments to help them compile this data.

53 OECD, 2024.
54 Africa Clean Energy, 2019.

- **Increase transparency** – To be accountable and provide clear measures of their performance, EPR systems should be transparent. Results of the monitoring should be made publicly available every year, including information on collection, recycling, and reuse rates.[55]

8.5. Additional policies to support e-waste management

On top of assigning financial and managerial responsibilities, government can adopt several policies to improve recycling practices within the country, including:

- **Monitor the quality of imported electronic goods** – A lot of e-waste is generated prematurely because of the poor quality of the products. Several governments have already regulated the quality of EEE imports. Technical, safety, and environmental standards can ensure that the mini grid satisfies basic quality checks. For more information on these standards, please refer to the toolkit *Legal and regulatory framework: Facilitating an enabling environment for solar mini grids in fragile contexts*. Given the pressing need for electrification, these standards should not be set too high; however, they should require a minimum level of quality to ensure that the mini grid will last.

- **Reduce import taxes on spare parts** – In some markets, importing spare parts is costly due to import duties and the need for supporting regulations. For example, Kenya requires spare parts to be supported by VeraSol quality assurance programme. This verification generally does not cover older components that are replaced by newer generations. This implies that it is hard to import spare parts for older versions of the product. Regulations should take into account the need to ensure the quality of EEE while ensuring that existing products within its markets can be adequately repaired. Additional policies to incentivise repair could be to reduce import taxes on spare parts.

- **Collaborate with neighbouring countries to build infrastructure** – Regional harmonisation can allow for greater economies of scale when managing e-waste. It can open more diverse markets and allow for information and knowledge sharing. Governments could work to establish legal frameworks, standards, and procedures to allow the transboundary movement of e-waste within a given region, potentially leveraging existing cooperation within regional economic communities.

55 OECD, 2024.

8.6. Pathways to begin the regulation process

Developing a fully comprehensive regulation on e-waste management can take years. The draft of the regulation can take many iterations between policymakers and practitioners before it is adopted. However, governments can follow these steps to begin drafting regulations:

- **Build interest among policymakers** – The first step is for the government to build interest on e-waste legislation. This can be done by using case studies of other countries or obtaining rudimentary data on current e-waste stocks within the country.

- **Take stock of the existing legislation** – The government should start by reviewing its current legislation on hazardous waste to see if it can be built upon. This also includes international rules on e-waste flows.

- **Map existing stakeholders** – It should conduct a thorough review of the e-waste value chain, including who the different stakeholders are and how interested in e-waste management they would be. It should also monitor all current e-waste management projects active within the country.

- **Take stock of the infrastructure** – Governments should engage with formal and informal recyclers in the country and in neighbouring countries to understand the gaps in the network.

- **Start collecting data** – Using help from international organisations such as UNITAR, governments should start collecting data on e-waste flows within the country. This allows the government to have a better grasp of the volume of e-waste that is currently imported into or generated within the country.

- **Draw on the experience of similar countries to draft regulations** – Many countries are currently developing e-waste regulations and can draw on the experience of other countries, such as Nigeria which has had a PRO, EPRON, since 2018, as well as technical assistance provided by international organisations such as UNITAR or ITU, who can also help build its capacity in terms of e-waste management.

9. Conclusion

As solar mini grids are deployed and EEE penetration increases in FCS, more and more e-waste will be generated. Unless it is properly taken care of, this e-waste can create an undue burden on exposed communities: materials contained in e-waste can contaminate soil and water sources, leading to negative health outcomes for nearby communities.

Once e-waste is generated, it should in theory be integrated into a formal e-waste disposal chain. This value chain consists of collection points and storage, transport infrastructure, and dismantling facilities, before the remaining fractions are sent to recycling facilities, potentially abroad. However, despite the value of some of the materials, the financial cost is generally too high for households or EEE manufacturers to dispose of e-waste safely. In practice, e-waste is generally dumped or burnt, with informal recyclers recovering the valuable parts of e-waste, including from cables and lead-acid batteries.

Given the high financial cost of e-waste recycling, it is currently unrealistic to assume that governments of most FCS have the capacity to set up a thorough e-waste recycling chain. Instead, any effort to set up this infrastructure would need to involve considerable collaboration between governments and EEE manufacturers, including solar mini grid developers.

More emphasis should be put on e-waste prevention. Solar mini grid developers have a key role to play in designing and maintaining the mini grid to extend its lifespan. Meanwhile, governments should start designing policies to regulate e-waste. Before setting up complicated EPRs, governments can start regulating the quality of solar mini grids installed. It can also start collecting data to obtain more information on the type and quantity of e-waste generated. Additionally, government can regulate the EoL management of more hazardous components of e-waste, such as lead-acid batteries, using the informal sector as a base to build on to ensure a higher collection rate. Finally, as EEE penetration increases, governments can start drafting more comprehensive regulations on e-waste that clearly define the responsibilities of each stakeholder in terms of financing and operating e-waste management.

10. Recommendations

10.1. Solar mini grid developers

- **The better tailored a mini grid is to a local community's needs, the more likely it is to be well maintained.** Therefore, it is important to prepare the ground by gathering data on energy demand, including how demand is likely to grow in the future.
- **Invest in quality equipment that will last.** While the costs must be taken into account, it is important to invest in equipment that has been proven to function in similar environments as the one where the mini grid will be rolled out in order to avoid early and costly dysfunctions.
- **Invest in equipment that can be easily repaired.** Equipment that can be easily repaired includes those with standardised parts and tools that are more easily available in the local market or can be more easily imported.
- **Set up remote monitoring systems.** Depending on how costly it is to travel to the mini grid, it is worth considering installing remote monitoring systems to avoid unnecessary maintenance trips.
- **Train local technicians to deliver everyday maintenance.** Local technicians can serve as a first line of defence against failures, with more expert technicians conducting more complex maintenance activities and dealing with emergencies. This can help reduce the cost of traveling to the mini grid to conduct routine maintenance or initial investigations of emergency alerts.
- **Develop a plan to dispose of batteries.** The most hazardous components of the mini grid are batteries. Developers should ensure that they have a plan to dispose of them safely even in the absence of e-waste management infrastructure in the country.

10.2. Development partners

- **Set quality standards for mini grid developers developers**, both quality control and repairability standards. This ensures that the grid can last as long as possible.
- **Ensure that the developer has a plan to dispose of batteries**, especially lead-acid batteries. This plan should be realistically costed, with disposal partners – such as dismantling and recycling facilities - appropriately selected.
- **Monitor and evaluate developers' e-waste strategy**, regularly auditing their maintenance, repair and takeback processes.

10.3. Governments

- **Set appropriate quality standards for the mini grids approved in the country.** This requires balancing the cost of the mini grid against the risk of failure if the quality of equipment is too low. This assessment should take into account the cost of the e-waste generated if mini grids fail prematurely.

- **Engage with the informal sector and train workers to help improve working conditions.** These trainings can be designed with the help of international organisations active in this space. Training can be done to improve recycling standards, covering the safe use of protective equipment and building awareness on the risks related to e-waste.

- **Build interest among policymakers.** Government will need to build interest on e-waste regulation. This can be done by using case studies of other countries or obtaining rudimentary data on current e-waste stocks within the country.

- **Take stock of the existing legislation and regulations.** The government should start by reviewing its current legislation and regulations on hazardous waste to see if it can be built upon. This also includes international rules on e-waste flows.

- **Map existing stakeholders.** Government should conduct a thorough review of the e-waste value chain, including who the different stakeholders are and how interested in e-waste management they would be. It should also monitor all current e-waste management projects active within the country.

- **Take stock of the infrastructure.** Governments should engage with formal and informal recyclers in the country and in neighbouring countries to understand the gaps in the network.

- **Start collecting data.** Using help from international organisations such as UNITAR, governments should start collecting data on e-waste flows within the country. This allows the government to have a better grasp of the volume of e-waste that is currently generated in the country.

- **Draw on the experience of similar countries to draft legislation or regulations.** Some countries already have functioning e-waste regulations, such as Nigeria which has had a PRO, EPRON, since 2018, and their experiences can be valuable learning tool for countries now embarking on developing e-waste regulations. Technical assistance is also available from international organisations, who can also support on developing e-waste management capabilities.

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State Fragility initiative

IGC

The **State Fragility initiative** (SFi) is an International Growth Centre (IGC) initiative that aims to work with national, regional, and international actors to catalyse new thinking, develop more effective approaches to addressing state fragility, and support collaborative efforts to take emerging consensus into practice. SFi brings together robust evidence and practical insight to produce and promote actionable, policy-focused guidance in the following areas: state legitimacy, state effectiveness, private sector development, and conflict and security. SFi also serves as the Secretariat for the Council on State Fragility.

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