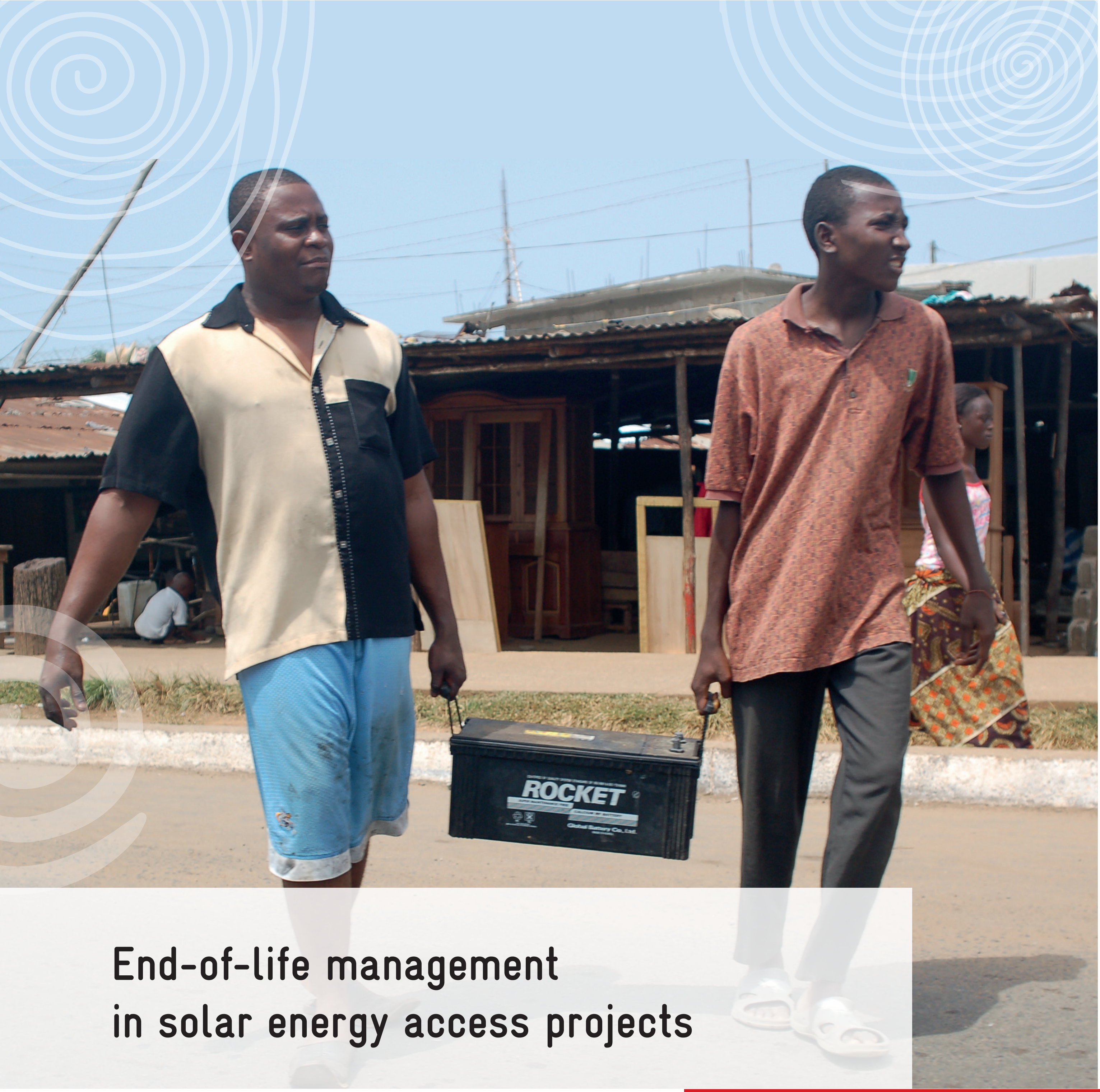

End-of-life management in solar energy access projects

Measures catalogue

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0 Executive summary

Enabling universal access to modern and clean forms of energy (SDG 7) ranks high on the global agenda and is supported by various donors and implementing organisations. Through these efforts, large numbers of energy access installations such as solar home systems and mini-grids are being deployed. While this yields multiple socio-economic benefits, it also brings new waste management challenges to rural and remote communities: Once obsolete many components turn into hazardous waste that require separate collection and adequate treatment. However, modern waste management systems are still widely absent in most off-grid areas. While this situation is recognised by many donors and implementing partners, the topic of sound e-waste management is complex and encompasses many technical, legal, logistical and economic aspects.

This measures catalogue aims at supporting planners, managers and operators of solar energy access projects in planning, designing and conducting waste related activities with a view of mitigating hazardous waste and pollution risks associated with the life-cycles of energy access projects. To do so, it provides an overview of the end-of-life (EoL) environmental and safety challenges from solar off-grid equipment. It also introduces the ethical and economic background of Extended Producer Responsibility (EPR) and presents the major entry points for improved EoL management of solar system components.

These entry points are structured in nine main measures and seven supporting measures, namely:

1. Use of **high-quality** and **durable** equipment
2. Use of **repairable** and recyclable system **designs**
3. Use of equipment with **less hazardous substances**
4. Taking informed **battery decisions**
5. Collection systems based on **warranties** and servicing structures
6. Collection and recycling through **third parties**
7. Sector **co-ordination**
8. **Solution** pioneering
9. **Policy** support

Each main measure describes a potential intervention that can have a measurable positive impact on end-of-life management patterns and can therefore be either planned and implemented as standalone, or in conjunction with other measures. Supporting measures such as baseline assessments, stakeholder workshops and awareness raising likely have a very limited positive impact when conducted as standalone. Nevertheless, they are often decisive stepping-stones for implementing one or more main measures described in this catalogue.

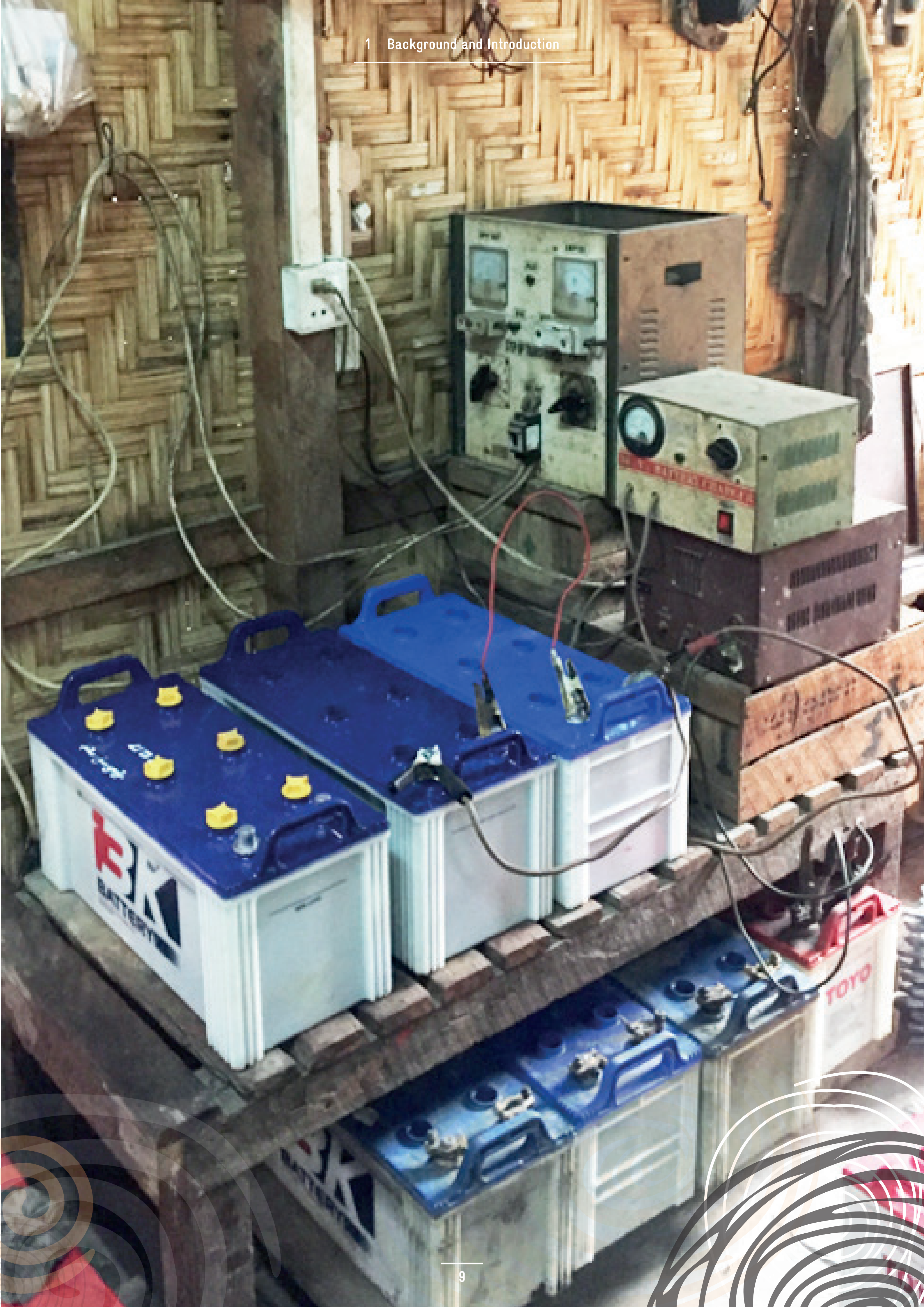
1 Background and introduction

To achieve the sustainable development goal (SDG) N° 7 on 'access to affordable, reliable, sustainable and modern energy for all' by 2030, most low- and middle-income countries launched ambitious energy-access initiatives. While grid extension is a key element of such strategies, there is widespread consensus that many rural areas require tailored off-grid solutions such as mini-grids or solar home system (SHS). In that context, many international donors support low- and middle-income countries to develop and roll-out solar off-grid projects. These concerted efforts undoubtedly advance the world's aim to achieve SGD 7 and yield mutual socio-economic benefits in off-grid areas. But as a side effect, solar off-grid installations bring new waste management challenges to rural and remote communities: Once obsolete the components of solar home systems turn into hazardous waste that requires separate collection and adequate management. Modern waste management systems are, however, still widely absent in most off-grid areas, which gives rise to the concern over pollution and safety issues from hazardous e-waste and batteries left behind or being mismanaged. Many donors, off-grid electrification projects and solar companies have already identified this challenge and various approaches and measures have been piloted to mitigate these risks in individual projects and areas. Nevertheless, the topic of e-waste management is complex and encompasses many issues around collection logistics, treatment technologies, disposal capacities, financing mechanisms and monitoring. This complexity makes it difficult for project managers to take effective measures. In addition, roles and responsibilities of energy access projects and their contracted companies (e.g., equipment suppliers, installers) are often not fully specified in local policies and regulations.

Solar off-grid installations bring new waste management challenges to rural and remote communities.

This measures catalogue aims at supporting managers of solar energy access projects in planning, designing and conducting waste related activities. To do so, this document provides an overview of the end-of-life (EoL) environmental and safety challenges from solar off-grid equipment. It also introduces the ethical and economic standard of Extended Producer Responsibility (EPR), it presents the major entry points for improved EoL management of solar system components as well as supporting measures.

The study is held in a concise format focusing on main concepts and approaches without going into technological or process details. While each presented concept and measure usually encompasses a variety of steps, the document aims at giving a structured overview and conceptual backgrounds rather than a step-by-step implementation guidance. In any case, national and local framework conditions always need to be considered additionally. The content of this catalogue is based on case studies, published literature, as well as practical project experiences from various energy access and e-waste management projects and initiatives.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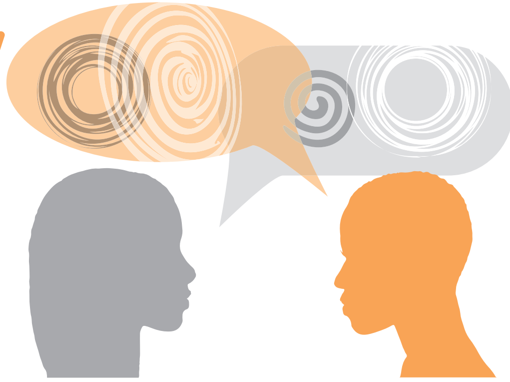
2 Rethinking our responsibility



Solar energy access projects aim to supply people with renewable energy, improving livelihoods and setting up a sustainable technology.

But…

1
Who has thought about where the PV-system components will go at the end of their lifetime?

2
Will these parts be collected and if yes, by whom?

3
Can the components be repaired and reused?

4
Will these parts be recycled and if yes: at what cost and standards?

As a planner / manager / operator of one or more solar energy projects, maybe you know the answers to the above-mentioned questions, but you may wonder

- about the exact EoL challenges of the individual system components;
  » Section 2.1
- who is responsible for taking what measures to improve the EoL management;
  » Section 2.2
- how to mitigate risks and / or assume full responsibility,
  » Section 2.3
- what the basic economic considerations are when planning for and implementing EoL management measures?
  » Section 2.4

The study addresses these concerns in Sections 2.1 – 2.4.

2.1 End-of-life challenges of off-grid electrification equipment

Off-grid electrification equipment is made up of various components with differing lifespans. The components will turn into waste with more or less hazardous properties (see Table 2.1), requiring special treatment and disposal.

A common challenge of the listed off-grid electrification equipment is the lack of incentives for collection and environmentally sound recycling. While this leads to components commonly being left behind (dumped, littered) with detrimental effects on the environment and human health, other components are likely to be collected but treated with sub-standard methods creating significant pollution problems in recycling hot spots. Additionally, adequate EoL management of the electrification equipment is particularly unlikely in remote and crisis prone areas. Thus, the introduction of off-grid electrification equipment is typically associated with an introduction of a waste challenge, if no systematic component repair, take-back, adequate recycling and safe disposal options are (put) in place. It is certainly possible to successfully tackle the challenge by addressing the combined measures described in this catalogue. In this case, solar off-grid projects might help to significantly modernize waste management systems in many rural and remote areas with potential positive spill-over effects on the treatment of other (hazardous) waste types.

2.2 Extended producer responsibility as underlying concept

The concept of EPR implies that producers, commonly defined as those who bring equipment onto a national market for the first time, are responsible for the associated environmentally sound EoL management. It is noteworthy that – for the operationalization of EPR – producers shall collect and manage equivalent amounts of the product type(s) they bring onto the market, rather than solely collecting own branded equipment. This responsibility may be fulfilled either individually (by own take-back schemes and recycling efforts), or collectively by cooperating with other producers. In a similar manner, in some countries, producers and importers are held accountable for EoL management by charging fees upon introduction of their equipment. These fees are collected in a fund (usually controlled by a Producer Responsibility Organisation (PRO), sometimes controlled by the government) that finances environmentally sound collection and recycling of e-waste.

Table 2.1 Indicative lifespans, material compositions and EoL challenges of off-grid solar power installations

Component groups	Expected Lifetimes	Material Composition	Main End-of-Life challenges in unregulated markets[1]
PV panels	> 10 years	Crystalline silicon, glass, aluminium, copper, trace elements (indium, tin, gallium…)	Typically, not collected, since full recycling is currently not profitable. Only the aluminium frame and cables may be removed and recycled at an economic gain. Although industrial processes for management of the panels exist in various industrialised countries (separation of glass from crystal silicon and back foils; recycling of glass; co-processing of residual waste in cement kilns) the process is associated with net costs.
Control devices	5 – 15 years	Printed circuit boards (PCBs), solder paste, various electrical and electronic components, plastics	Probably collected and partly recycled. Control devices contain PCBs and electronic components that contain some copper and other valuable metals. These metals can be recovered in large scale smelters (in Europe, Asia, N-America) and many recyclers organise regular shipments to such destinations. Some recyclers might also refer to local treatment using hazardous chemicals such as cyanide and mercury. While such processes can recover some of the embedded metals, environmental impacts from the discharge of chemicals and pollutants are often very high. Depending on the material composition, the cases can either be recycled (e.g. steel, plastics like ABS) or require disposal (composite materials, fibreglass…).
Batteries	2 – 6 years	Lead-acid batteries (LABs): lead, lead-oxide, plastics, electrolyte (sulfuric acid). Around 65% of the weight of a LAB is lead and lead-oxide and 10 – 15% sulfuric acid.	Used LABs (ULABs) are commonly collected to recover lead but often inadequately recycled under high EHS (environmental, health and safety) risks. Unsound ULAB recycling is classified as one of the world's most polluting industries (Bernhardt and Gysi 2016). It is important to note that unsound recycling is not only limited to informal sector processes, but also to many registered industrial facilities applying insufficient pollution control measures. Exposure to lead is likely to cause severe damage to brain and kidneys and can be lethal. Sulfuric acid exposure causes skin burns, eye damage as well as an acidification of the environment.
		Li-ion batteries (LIBs): graphite, various organic substances, copper, aluminium, lithium, plastics.	Used LiBs (ULIBs): Typically, not collected, little recycling value and thus unattractive for local and global recycling markets. This is even more pronounced with LIBs that contain no cobalt (e.g. lithium-iron phosphate batteries (LFP). Overcharging, high temperatures and physical stress on the battery cells can cause a thermal runaway, fire or explosion. ULIBs maybe recycled at specialized facilities in Asia, North America or Europe, which is associated to shipping and recycling costs. Transport to such facilities requires extensive fire safety precautions and shipping companies generally reject such transports.
Cables	> 10 years	Copper, plastic (PVC, PE) insulation	Collected and often openly burnt by informal sector players to obtain and sell the copper (scrap), causing hazardous dioxin and furan emissions. Mechanical ways of cable processing exist in many countries (shredding, stripping), but are commonly less profitable.
Equipment (lamps, radios, fans, TVs…)	2 – 10 years	Various plastic types, aluminium, copper, various electrical and electronic components such as microchips	Often uncontrolled disposal of WEEE (waste electrical and electronic equipment). Some collection with the aim to recover copper, aluminium and high-grade PCBs – often at EHS risks.

Source: Adapted from (Manhart et al. 2018)

1 Unregulated markets are settings where legal obligations to set-up and run collection and management schemes for environmentally sound management of e-waste are either not in place, or insufficiently enforced.

The concept of EPR is undisputed and regarded as an effective means to translate the polluter-pays-principle into practice for products and waste streams that pose substantial risks to human health and the environment. In the 1990s Germany was one of the first countries to introduce EPR for packaging (Bünemann et al. 2020). In the last decades, the concept of EPR has been increasingly taken up by national policy makers of low- and middle-income countries including an uptake into legislative requirements. For energy access projects it is also noteworthy that – in some jurisdictions such as Nigeria, Ethiopia and the EU – the legislative frameworks differentiate between electrical and electronic equipment (EEE) and batteries, with different sets of laws and EPR requirements.

As the principles of Extended Producer Responsibility are widely accepted, they should also be applied in off-grid electrification and GOGLA, the Global Off-Grid Lighting Association, has committed to EPR as a cornerstone-principle for their members in 2014 already (AGM 2014). Implementing EPR is typically not a one-off measure, but a continuous learning and adjustment process in order to respond to developments in material streams, options for collection, recycling and waste management (Bünemann et al. 2020).

Despite the large interest in EPR, many low- and middle-income countries have either no mandatory EPR scheme for electrical and electronic equipment yet or have not yet rolled-out or enforced legal EPR requirements (Blair et al. 2021).

Despite this implementation gap, EPR should be treated as the major underlying philosophy for players bringing electrical and electronic equipment onto the market for the first time: Ideally, these players should care for the collection and environmentally sound management of equivalent amounts of end-of-life devices in their country of operation.

With regard to solar off-grid projects, this should lead – in an ideal scenario – to a situation where each project keeps track of the amount of equipment brought onto the market, and organises the collection and recycling of equivalent amounts of batteries, converters, cables, PV-modules etc. This concept is sometimes also referred to as ***'bring-one-in, take-one-out'***. This responsibility may be fulfilled by the project itself (e.g. own take-back scheme), through third parties (agent, local logistics and recycling company), or collectively with other market players (through a PRO).

Ideally 100% of the volume brought onto a national market should be collected. As this figure is illusionary in most world regions, official collection targets are typically lower. In the EU, collection targets for EoL electrical and electronic equipment (WEEE Directive 2012/19/EU) were at 45% until 2018 and are at 65% today. For portable batteries (EU 2013), collection targets are at 45% and planned (EC 2020) to be increased to 65-75% in the next years (no final decision yet). Basis of the percentage-calculation is the achieved annual collection volume and the average weight of equipment placed on the market in the three preceding years.

In addition, the EPR philosophy also involves further measures that effectively help to reduce EoL and pollution problems[2]. This entails measures around product and system design and warranties that help to reduce waste generation, improve repairability and recyclability.

Some useful further reading on EPR is given in chapter 5.

Box 2.1 The EPR-philosophy in a nutshell

The players that bring equipment onto the market are (ethically) responsible…

- to supply durable and high-quality products and systems (incl. warranty & maintenance)
- to take efforts to reduce the amount of hazardous substances in their products
- to use system designs that support repairability and recyclability
- to ensure collection and environmentally sound recycling of equivalent amounts of end-of-life devices (setting ambitious collection targets)

[2] Although these other aspects are often not an explicit focus of EPR legislation, it is mostly an indirect aim that producers – in their attempt to keep costs of end-of-life management low – apply these principles.

2.3 Balancing effort & risk mitigation

In many cases, it is difficult to immediately and fully put into practice the EPR-philosophy as outlined in Box 2-1. The reasons may be:

- The lack of alternatives to phase-out components with hazardous elements: Electrical and electronic components, batteries and PV modules do require a wide range of materials for their functionality, whereof some have hazardous properties and currently cannot be phased-out easily for technical reasons.
- Limited funds and purchase power for more sustainable and durable products: Durable products are sometimes significantly more expensive in their acquisition than less durable alternatives. There may be too little demand or limited purchase power for preferable alternatives.
- The insufficient development of EoL management options: In-country responsible EoL management options are sometimes insufficiently developed. This either requires exports for treatment in other countries, or application of 'second-best' solutions such as controlled hazardous waste disposal.

While such challenges may be significant, there are no valid excuses to ignore issues around unresolved EoL management. It is the ethical responsibility of producers (see definition in Section 2.2) and project managers who select producers to apply the EPR philosophy. Efforts to implement EPR should be in-line with the national legislation and effectively mitigate EoL management challenges and risks to human health and the environment.

In a context, where the implementation of EPR principles seems particularly challenging, a so-called risk mitigation approach can help decision-making on the type of equipment and on EoL measures. For instance, in situations where collection and managing equivalent amounts is not possible in the short or mid-term, it is recommended to initially focus on waste types and fractions with the highest pollution and safety risks. For solar system components (see Table 2.1), batteries most likely constitute the first focal point, since they normally have the shortest lifetimes among the components, while being quite problematic in terms of their material composition, safety aspects and recycling processes. All common battery types, namely LABs and LIBs, are concerned.

2.4 Economic considerations

For improving EoL management of off-grid solar equipment, it is important to understand that most existing waste management patterns are determined by economic drivers. This can be illustrated by the following examples:

- Non-valuable waste types such as damaged lithium-iron phosphate batteries (LFP batteries), PV panels and lamps (see Table 2.1) are often not collected and treated separately because (formal and informal) waste collectors and recyclers have no direct benefit from collection and recycling. While these waste types can technically be recycled, the treatment processes are more costly than the value of the recovered raw materials. Data from the Global LEAP Challenge (Blair et al. 2021) revealed e.g. that at end-of-life, an entry level solar lantern has a negative value of US$-1.36 / unit. Subsequently collection and treatment only occurs in settings where one or more players are willing and / or obliged to care for these waste types and cover the additional costs (see examples 1 and 3 in Figure 2.1).

- While the collection of (metal) scraps is usually well developed in urban centres, collection networks are often less developed in rural communities. This is because the logistical costs for collection and aggregation of scrap are much higher in sparsely populated areas, making it unattractive for many operators.

- Informal recyclers often refer to open burning practices to liberate metal cores of cables. This step is often necessary to access scrap metal markets as most traders and smelters only accept scrap metal deliveries free from other materials. While other (non-polluting) liberation technologies are available, they are all associated with higher investments and operational costs. As informal recycling activities are often poverty driven, operators mostly decide for a strategy that maximises profits – even if the process is associated with severe pollution (see example 2 in Figure 2.1).

- Implementation of EHS standards is often associated with quite substantial investments and operational costs. Therefore, recyclers that are in competition with other companies (incl. the informal sector) commonly experience pressure to lower costs to levels where full implementation of all EHS safeguards is difficult or even impossible (see example 4 in Figure 2.1).

- In turn, there are niche markets where recyclers do not only compete on price, but also on quality. In many low- and middle-income countries where minimum standard are not thoroughly enforced by authorities, markets mostly thrive on institutional policies (e.g. corporates, educational institutes) aiming at a responsible business conduct, including a sound management of generated wastes.

For solar energy access projects, this basically means that an implementation of the EPR philosophy as illustrated in section 2.2 will most likely lead to additional costs compared to the status quo. While cost issues might be a hurdle in many cases, it is recommended to communicate them transparently to partners and donor agencies, and to work towards the understanding that proper waste management comes at a cost, and that avoiding these costs will most likely lead to sub-standard and polluting waste management[3]. However, the EoL management costs can be reduced by

Additional costs should be communicated transparently to partners and donor agencies

- **3.1** investing or setting minimum standards for durable equipment, requiring less replacement and thus generating less total waste over time, by »
- **3.2** making equipment repairable and recyclable, by »
- **3.3** minimizing hazardous substances, by »
- **3.4** making informed decisions on the battery types used in a particular location and by »
- **3.5** aligning with existing collection and warranty systems. To further optimize efforts towards better EoL management, projects can »
- **3.6** use market-based collection and recycling systems, »
- **3.7** foster sector coordination, »
- **3.8** engage into solution pioneering as well as »
- **3.9** policy support. »

Each of these additional activities come at a cost, but will also internalize expensive externalities, foster the local waste management infrastructure, create new jobs and make solar energy access systems a more genuinely sustainable solution. Experiences from various countries show that EPR – once rolled-out at larger scale and for all types of batteries and electrical and electronic products – can be quite cost efficient, resulting in lower additional costs per device.

[3] Unsound waste management is a classic example of cost externalisation: While low standards allow savings on the level of individual operators, adverse impacts on, and costs for human and environmental health can be substantial.

Figure 2.1 Common examples of cost externalisation in e-waste handling

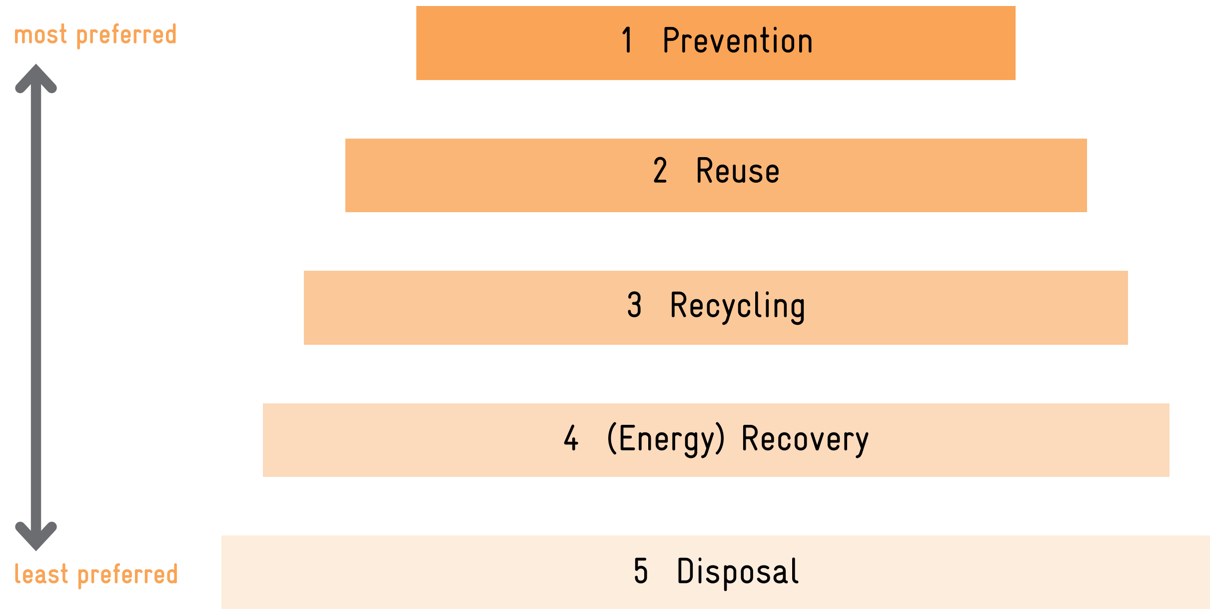
Four examples of e-waste related pollution that can be attributed to externalisation of costs: 1: EoL lamps that are not collected but dumped and burned together with other waste. A major underlying reason is that no player is willing to organise collection and sound management which would be attributed with net costs. 2: Open burning of cables to recover copper. While less polluting methods exist, they are more costly and do not allow significantly higher material recovery. 3: Dumping of residues: The valuable components have already been extracted and the non-valuable and hazardous tubes are dumped uncontrolled. 4: Severe stack emissions from an industrial battery recycling plant. Better emission controls would require investments and lead to higher operational costs.
Photos 1 – 3: © Öko-Institut e.V. 4: © Centre de Recherche et d'Education pour le Dévelopment (CREPD)

3 Major measures for improved EoL management in off-grid solar energy projects

The following chapters (3.1 – 3.9) present a catalogue of concrete measures to facilitate or to improve EoL management of PV-system components in off-grid electrification projects. The study provides background information and highlight measures in the overview tables at the beginning of each sub-chapter for quick and easy browsing of the document. Moreover, the study highlights examples or practical advice in the additional text boxes.

The described measures consider the widely accepted 5-step waste hierarchy, where waste prevention, reuse and recycling are given priority over energy recovery and disposal (see Figure 3.0). Accordingly, this chapter starts with measures facilitating waste prevention and reuse (sections 3.1 and 3.2) and entails various measures for recycling (sections 3.5 – 3.8). The measures described in sections 3.3, 3.4 and 3.9 are cross-cutting in nature.

Figure 3.0 The 5-step waste hierarchy



Source: Adapated from Öko-Institut

3.1 Use of high-quality and durable equipment

Table 3.1 What and why? High-quality and durable equipment

FAQ	Answer
What?	All parts of a solar energy access equipment.
Why?	Deploying high-quality and durable equipment prolongs the lifetime of PV-system components, reduces waste through less frequent replacement-needs, reduces system failures, down-times and service costs.
Context?	Early project stage/procurement: Quality and durability standards may be included in the technical specifications or as an evaluation criterion in the procurement of equipment. Longevity and environmental performance may be criteria set in Results-Based Financing (RBF).
Cost Implications?	Usually higher purchasing costs, but often equal or even lower life-cycle costs (less servicing, less repairs and replacements thus cost savings in the medium to long run).

Source: Own compilation

As presented in Table 2.1 (see chapter 2.1), the various solar system components evince different average expected lifetimes. These could be prolonged by setting a greater focus on the quality of the procured or supported equipment. There are international quality standards that may be referred to select eligible suppliers or applicants.

The Energising Development (EnDev) Programme, a global energy access programme typically refers to the VeraSol Quality Standards (Verasol 2021a) for off-grid solar equipment ranging from lanterns to solar home systems (Haack et al. 2021; Schröder and Gaul 2021). VeraSol tests and certifies solar energy kits with PV-modules of less or equal to 350 W peak (Verasol 2021b) using the test methods defined by the standard IEC TS 62257-9-5: *Laboratory evaluation of stand-alone renewable energy products for rural electrification* of the International Electrotechnical Commission (IEC). This standard is an updated version of the widely used Lighting Global Quality Standard, originally developed by the World Bank Group (Verasol 2020). IEC TS 62257-9-5 describes design and durability aspects, quality assurance principles, warranty requirements, quality testing, market check methods and reporting requirements. Concretely, to comply with the VeraSol standard, products are sampled and after a visual inspection, the equipment is tested for aspects such as battery and cable quality, water ingress protection, durability of moving parts and sturdiness of portable components (IEC 2018; Lighting Global 2018).

Furthermore, the 2018-IEC norm defines standards for end user support, truth in advertisement, minimum warranty periods for pico-products and SHS kits and Pay-as-you-go (PAYG) models (see also report Section 3.5). After every two years, renewal testing is required. For DC solar appliances like standalone TVs, fans, refrigerators, solar water pumps, VeraSol refers to Global LEAP test methods which include energy performance, quality, durability, safety and consumer protection (Verasol 2021b).

The 2018-IEC testing requirements are part of the larger IEC 62257 standards for Renewable Energy and Hybrid Systems for Rural Electrification, consisting of various parts and updates. The latest Technical Specification -9-8 (IECTS62257-9-8:2020) was published in 2020 and complements the 2018-norm by the following aspects (Lighting Global 2020): labelling requirements, PV module safety[4], requirements for systems with large PV modules or arrays (>240 W, open-circuit voltage greater than 35V or short-circuit current greater than 8A), requirements for battery specification sheets, compliance with standards for lithium battery safety, information about the date of manufacture, a statement on the replaceability of components for PV modules, batteries, lights or fuses.

[4] The novel PV module safety tests include: an increased visual screening and wiring inspection, test of the durability of markings for non-integrated modules, sharp edge test, screw connection test, impact test, bending or folding test if applicable as well as a hotspot endurance or partial shading test for modules over 10W.

Noteworthy, the EU is currently developing eco-design criteria for PV modules and PV inverters (EC 4/29/2021; Wade et al. 2021), too. These will set minimum quality standards for the European market, including standards for the energy yield (info / quantitative), durability, quality assurance of the production process, performance on long-term degradation, the ecological profile, repairability and recyclability. Individual countries may have already developed own standards, too. Recently, Nigeria has introduced national standards for solar PV components including a standard on Design Qualification and Type Approval for PV modules (NIS IEC 61215-2) (SON 2021). Amongst others, new types of PV modules need to go through rigorous outdoor quality testing, conducted by an accredited certification body. Uganda, respectively the Uganda National Bureau of Standards (UNBS) has also introduced national standards for plug-and-play Solar Home Systems, pay-as-you-go kits and other renewable energy kits of up to 350W in July 2021.

In general, procuring equipment with extended and long-term warranties is an indicator for quality and possibly for a service structure that could be used for repairs and systematic take-back of obsolete components (see also Section 3.5).

The 2018-IEC quality standard, also referred to by VeraSol, constitutes a good basis that you may refer to during your procurement or selection of solar electrification equipment providers. However, the VeraSol standard must be complemented by longer and differentiated warranties for batteries, criteria for systems larger than 350W and more elaborate standards on repairability, recyclability (see Section 3.2) and a more nuanced regulation of hazardous components (see Section 3.3).

If you have ongoing projects and equipment in use, you may start collecting information on the quality criteria that these components already fulfil, asking the service contractor to record or provide information about the lifetime of system components and costs for maintenance or replacement. This information may serve as a valuable reference base when comparing it to a procurement of higher-quality PV-components. Besides an analysis of costs, it should also be analysed where among the system components an increase of quality requirements helps most to extend the overall system durability.

Beyond applying quality standards for equipment, there should also be quality standards for the overall system design, installation, operation and maintenance (SON 2021). A technically correct set-up and regular maintenance positively influencing the lifetime of solar system components, too.

How to get started >>

Existing solar energy access projects »

- Interact with installation and servicing companies and personnel active in your project and country to identify most common quality / durability problems with energy access equipment (e.g. most common component failures,).
- Check if failure rates can be reduced by deploying different equipment models and / or by changing to equipment compliant with common quality standards (e.g. Verasol).
- If yes: Change procurement / financial support criteria accordingly.
- If not: Check if retrofits or regular maintenance can help to reduce failure problems

For solar energy access projects in the programming phase »

- Make common quality standards (e.g. Verasol) integral part of procurement / financial support criteria.
- Plan for high quality servicing and maintenance systems for installed equipment over prolonged time periods. Consider warranties of manufacturers and distributors, since they are a first indicator for product quality.
- Monitor failure rates during project implementation and try to detect typical hard- and software weaknesses. Further steps see 'how to get started for existing projects' above.

Box 3.1 Exemplary procurement text

Plug-and-play systems up to 350 W

The VeraSol Standard represents a good basis for solar off-grid installations up to 350 W. Following text might be used to request VeraSol compliance:

The supplier is required to deliver proof that quality and durability criteria according to the latest version of the VeraSol standard are complied with (e.g. by a valid VeraSol certification, or by respective proofs for all applicable criteria listed in IEC TS 62257-9-8, tested with the methods described in IEC TS 62257-9-5).

The VeraSol standard requires 2 years warranty for storage batteries. A practical way to ensure high quality batteries is to increase requested warranties to 3-4* years. Following text might be used:

A warranty of 3 years shall be given for the storage battery.

*Due to the higher average lifetime of Lithium-ion batteries, a warranty of 3 years for lead-acid, 4 years for Lithium-ion batteries might be requested. In any case informed battery decisions should be made (see section 3.4).

Off-grid solar installations bigger than 350 W

As the VeraSol standard and the respective IEC norms are only applicable for systems up to 350 W, bigger systems request adapted quality criteria. It is suggested to address the same categories as the VeraSol standard, complementing additional criteria if necessary.

Requirements could address following aspects:

- Truth in Advertising including transparent performance reporting
- Health and Safety requirements including circuit and overload protection, safety of individual components, ban of hazardous substances
- Battery requirements including correct labelling, protection, safety aspects and durability
- Quality and Durability requirements including physical ingress protection, water protection, durability of portable and moving components as well as cables, measures to avoid false installation
- Consumer information requirements including minimum warranties, user manuals explaining the components and replacements methods

The VeraSol standard addresses only plug-and-play systems. For all other off-grid solar installations systems it is recommended to include quality criteria to ensure correct dimensioning and installation of components. Oversizing of storage capacities can diminish the lifetime of batteries, whereas undersizing reduces the duration of electricity supply for end-users. False installation might also reduce the lifetime of system components. Following text might be used to address these issues:

The supplier is required to deliver proof that PV panels and capacities of the storage batteries are suitably dimensioned (To be proven by a self-declaration). Products must either be labelled or complemented by a short manual to support correct installation.

As with an increasing storage capacity the risk of a thermal run-away in Lithium-Ion batteries is higher, it is recommended to request a suitable temperature management system for installations bigger than 350 W. Following text might be used:

If products with power ratings bigger than 350 W use Lithium-ion batteries for storage, the supplier has to deliver proof that a suitable temperature management system is used (To be proven by a self-declaration including a description of the temperature management system).

3.2 Use of repairable and recyclable system designs

Table 3.2 What and why? Repairable and recyclable system designs

FAQ	Answer
What?	All components of a solar energy access equipment
Why?	Deploying repairable solar system components prolongs the lifetime of the equipment and reduces waste through less frequent replacement-needs. Procuring recycling-friendly components is an up-front investment in easier and cheaper EoL management of the equipment.
Context?	Early project stage/procurement: Ease of repairability and recycling can be included in the technical specifications or as an evaluation criterion in the procurement of equipment. The criteria may also be applied to Results-Based Financing (RBF).
Cost Implications?	Well repairable and recyclable system designs are usually not more expensive than other equipment. Related procurement rules might only rule out some low-cost and low-quality designs.

Source: Own compilation

For a good repairability, system components need to be designed in a way that trained personnel is able to carry out repairs with locally available spare parts and equipment. This implies that casings, e.g. of batteries and control devices, must be easy to open and connections should not be glued or welded. However, for safety reasons, some components, such as battery packs (fire and explosion risks, hazardous substances) should be protected from manipulations. Repairability may be tested with local servicing partners and recyclers. Using locally assembled equipment increases the likelihood of a later local repairability. There may, however, be a situation where a trade-off exists between local production and highest quality equipment.

In tenders, a minimum time (number of years) for the availability of spare parts and minimum requirements for repair services may be set. The VeraSol standards (IEC TS 62257-9-5; IECTS62257-9-8:2020) merely state that the product warranty shall explain how it will be executed '(repair, replacement, etc.)'. Recycling is not mentioned as far as this study can derive from the summaries of the standards published by Lighting Global (Lighting Global 2018, 2020). The current EU eco-design criteria, which are still under development (EC 4/29/2021), may soon constitute a good reference to source from for your procurement texts and for selecting suitable providers of solar equipment and related repair and recycling services.

Concerning recyclability, housing and structural elements made of mono-materials, such as sheet metal or plastics (e.g. ABS), have a higher likelihood of being recycled than composite materials such coated plastics or glass fiber reinforced plastics, which hardly are recyclable. Section 2.1 provides information about pollutants and the challenge with PVC in cables and batteries, which become problematic during improper recycling or disposal.

In some settings (e.g. equipment from local productions with plastic recycling capabilities), it can be considered to promote products made with recycled materials. E.g. plastic cases could be made with some recycled content (e.g. 25-50% recycled ABS). Such recycled-content approaches can have a significant pull effect on recycling markets and are particularly relevant for plastic[5].

There are reports that used Li-ion batteries may be repurposed and used as electricity storage. While such repurposing and reuse are theoretically good means to advance the circularity of off-grid equipment, this approach can only be recommended if repurposed batteries are proven to be safe for consumers. Safety concerns here are particularly related to fire safety risks. In addition, repurposing concepts that refer to used

[5] In contrast to metal recycling, plastic recycling is economically less attractive so that commitments by off-takers and downstream markets can greatly stimulate recycling in this field.

batteries from industrialized countries being used in low- and middle-income countries should apply effective safeguards ensuring that the approach does not violate international regulations related to hazardous waste shipment[6] and has proven net benefits for receiving countries. Net benefits are considered to be possible when the imported batteries either have a higher quality as the commonly used batteries in energy access projects, or the same quality at a lower price (Angliviel et al. 2021). Ideally, battery repurposing refers to used batteries sourced from the local market and by applying high quality standards. A standard for the evaluation for repurposing batteries is the standard (UL1974), which covers the sorting and grading process for battery packs, battery modules and cells as well as electrochemical capacitors that were originally used e.g. for electric vehicle propulsion and that are intended for reuse e.g. in energy storage systems.

For PV-modules, the most noteworthy development is the current development of eco-design standards for PV modules, whose draft (Wade et al. 2021) includes the following minimum requirements for repairability: (1) the possibility of replacing the bypass diodes in the junction box as well as (2) the possibility to replace the whole junction box of the module. The eco-design draft also includes minimum standards for the dismantlability of modules and inverters, specifying that manufacturers must report (1) on the potential to separate and recover the semiconductor, the cells, glass, encapsulants and the back sheet and (2) on measures to prevent breakage, enabling a clean separation.

How to get started »

Existing solar energy access projects »

- Give samples of your off-grid electrification equipment to local repair experts / workshop and recyclers. Collect their feedback on reparability and recyclability.
- Translate this feedback in requirements for further equipment deployment
- Train local repair experts / workshops in servicing off-gird solar products
- Support maintenance and repair of your off-grid equipment (e.g. through warranties and servicing arrangements).
- Support improved spare part availability for off-grid solar products

For solar energy access projects in the programming phase »

- Set minimum requirements for the repairability and recyclability of the equipment brought onto the market through the project (e.g. by using the text in Box 3-2) as a mandatory add-on to the VeraSol standards, which only ask to mention repair and replacement in the product warranty.
- Do practical testing with equipment, support repair experts / workshops, equipment maintenance and spare part availability (see 'how to get started for existing projects').

[6] Violations are likely to occur in cases where untested used batteries are shipped to be used as storage (e.g. in energy access projects) in other countries. According to international practices, untested used batteries are considered as hazardous waste and any transboundary movement requires notification according to the procedures of the Basel Convention. Shipments of hazardous waste from the EU to non-OECD countries are generally considered illegal through the Basel ban Amendment and the EU Waste Shipment Regulation. Used batteries may only be shipped if the used batteries have been tested and classified as fully functional products.

Box 3.2 Repairability and recyclability of solar energy access equipment

Field testing of this measures catalogue in Benin resulted in the identification of a good product example for reparability and recyclability. The product in question is a simple solar lantern for school children consisting of a Lithium-iron phosphate (LFP) battery in a highly robust steel casing closed with simple screws. The smallest model includes a small solar panel at the backside of the casing. Slightly bigger models have separate PV components to be connected with the luminaire itself. The light source is an energy efficient LED module placed behind a robust acryl glass light distribution element which is hardly crushable in practice.

Repairable and recyclable solar lanterns in Benin. Photos: © Öko-Institut e.V.

The LFP battery, solar and LED components are imported from East Asia. However, the solar lanterns are finally assembled and tested in Benin leading to local value creation. Also, the steel casing is produced on site. The lanterns are designed in a way that the steel casing can be easily opened with a common screwdriver (e.g. for a battery exchange). Furthermore, the lanterns consist of few standardized components that are used for all models. They can be easily replaced if needed, and end-of-life models can be utilized as source of spare parts for repairs. The company holds a country-wide network of agents that re-collect and exchange broken luminaires during the warranty period. Warranty equipment is channeled to a reconditioning plant in Burkina Faso that provides a refurbishment service of the luminaires for several francophone countries (Benin, Togo, Côte d'Ivoire, Mali, Sénégal).

To effectively integrate repairability and recyclability requirements in procurement, the following sections may be used for tendering documents:

The equipment shall be designed in a way, trained personnel can conduct repairs with the use of locally available tools. Amongst others, this requires that the equipment is designed in a way that connections between parts and components are not glued or welded. This requirement does not apply to battery packs, or any other components where opening by untrained personnel may cause health and safety risks such as electrical shocks and fire.

The supplier must provide guidance documents/manuals on how to conduct most common repair operations and keep this information online available for at least [x] years. The supplier guarantees that spare parts are kept available for at least [x] years after delivery.

Cases and structural elements of the equipment shall be made from a mono-materials such as metal or ABS and shall not be painted or coated. Laminated materials and composite materials shall be avoided.

The suppliers of controllers and inverters (and possible also those of other equipment with a housing) is encouraged to use at least 25% recycled plastics for cases and structural elements. Related claims are to be supported by a recycled-content certificate issued by a third party.

3.3 Use of equipment with less hazardous substances

Table 3.3 What and Why? Less hazardous substances

FAQ	Answer
What?	All components of a solar energy access equipment
Why?	Minimizing the content of hazardous substances in products (and of constitutes that are likely to generate hazardous substances during end-of-life management) significantly helps to reduce pollution problems during end-of-life management.
Context?	Early project stage / procurement: Ask for EHS-preferable alternatives to components with hazardous substances whenever available e.g. in the technical specifications or as an evaluation criterion in the procurement of equipment. These criteria may also be applied to Results-Based Financing (RBF).
Cost Implications?	Compliance with RoHS-6 and PVC free cables is standard for the many of producers and should only have a minor impact on equipment price (if any). Compliance with RoHS-10 might still limit product choice in some world regions and subsequently have an impact on equipment price.

Source: Own compilation

Hazardous substances in electrical and electronic equipment and batteries (incl. off-grid electrification equipment) such as heavy metals (e.g. lead, hexavalent chromium) and organic pollutants (e.g. brominated flame retardants) are problematic as they are likely to be released during inappropriate recycling and disposal, negatively affecting human and environmental health. In general, pollution from processing end-of-life electrical and electronic equipment and batteries can be classified in three types:

- Primary pollution: Emission & release of hazardous substances that are part of the equipment
- Secondary pollution: Emission & release of substances that are generated during unsound processing of end-of-life equipment (e.g. in open fires)
- Tertiary pollution: Emission & release of substances that are used as process agents in treatment processes (e.g. cyanide, acids)

Despite all efforts to improve collection and recycling, it must be kept in mind that perfect take-back and recycling systems do not exist, and that unsound management is still a reality in all world regions. In that context, product design can greatly reduce the amounts of substances effectively reducing primary pollution risks. Also, secondary pollution risks can partly be influenced by product design.

In terms of phase-out of hazardous substances, the so-called RoHS-Directive (RoHS = Restriction of Hazardous Substances)- (2002/95/EC – ROHS 1) was passed in the EU in 2003 and led to widespread ban of lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB), polybrominated diphenyl ether (PBDE) in electrical and electronic equipment. This RoHS-Regulation was adopted by many other jurisdictions, including California, S-Korea, China, India and Ghana and initiated a global design shift away from these substances. In a recast of the EU-RoHS-Directive in 2015, the initial list of 6 substances (RoHS-6) was expanded to 10 with four more substances being banned from electrical and electronic equipment in the EU now (RoHS-10).

Solar energy-access projects should aim at only using RoHS compliant equipment, ideally complying with RoHS-10 as set out in EU Directive 2015/863. It must be noted that the EU RoHS Directive does not apply to batteries and most solar panels[7]. For this reason, the projects should additionally take the following measures:

- Use PV-panels that are free from lead, cadmium and other RoHS regulated substances. While this effectively excludes cadmium-telluride (CdTe) panels, this type of panels is predominantly used in industrial, large-scale solar parks and are more expensive: Thus, the requirement is most like not limiting technology options for solar home systems where cadmium-free panels from crystalline silicon (Csi) represent >95% of the market.

- Take informed decision on the choice of batteries. While lead-acid batteries contain high amounts of lead and sulfuric acid (both hazardous), Li-ion batteries contain cancerogenic metals and various hazardous organic substances. More details on this topic is given in section 3.4. In any case batteries shall not contain more than 0.0005 % mercury and 0.002 % of cadmium by weight, which is also stated in the VeraSol Quality standards, referring to the EU Battery Directive (Lighting Global 2018). In case batteries contain more than 0.004 % lead, they should be marked with the chemical symbol for lead (Pb) in a well visible manner. These requirements are common practice and legal requirement in the EU (EU 2013).

In terms of avoiding secondary pollution from unsound EoL processing, the choice of cables (and their insulation) is relevant: While many cables are insulated with PVC, this material generates high amounts of dioxins and furans when heated or burned. As open burning of cables is a common practice in many settings (see Table 2.1), PVC free designs can help to mitigate this pollution risk. Similar aspects apply to PVC in lead-acid batteries[8].

The upcoming eco-design directive (Wade et al. 2021) lists standards on hazardous substances disclosure in conjunction with the NSF 457 Criteria for PV modules and inverter, the NPCR 029 v.1.1 criteria 7.4, the IEC 62474 Declarable Substance List, the REACH SVHC and REACH candidate lists. Once the eco-design directive is available, it may serve as a reference.

In conclusion, the VeraSol Quality Standard focuses on hazardous substances in batteries only, while hazardous substances in other components such as PV panels and cables require attention, too.

Despite all efforts to improve collection and recycling, it must be kept in mind that perfect take-back and recycling systems do not exist.

[7] PV panels installed by professionals are excluded from the EU RoHS scope, which basically excludes all. PV panels used commercial, industrial and residential applications.

[8] Formally some producers used PVC to separate anodes and cathodes ('plate separators'). In recycling processes, the plate separators are charged to smelting furnaces together with the lead bearing materials International Lead and Zinc Study Group 2013. If PVC is used, this results in dioxin formation and emissions. While most producers changed their designs to other materials (e.g. PE, glass-mates), some producers still use PVC.

How to get started >>

For existing projects »

- Identify how your existing products perform in terms of hazardous substances and what associated EoL challenges are to be expected.

For solar energy access projects in the programming phase »

- Include into your procurement or minimum standards: the VeraSol Quality Standard on batteries as well as requirements for PVC-free cables and PV modules which are free from ROHS-regulated substances.

Box 3.3 Substance requirement for procuring of off-grid solar power equipment

To effectively integrate common substance restriction requirements in procurement, the following passus may be used for tendering documents:

Equipment (excl. batteries) shall not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB), polybrominated diphenyl ethers (PBDE), bis(2-ethylhexyl) phthalate (DEHP), butyl benzyl phthalate (BBP), dibutyl phthalate (DBP), and diisobutyl phthalate (DIBP). The maximum concentration values tolerated by weight in homogenous materials is 0.1% for each of the listed substances and 0.01% for cadmium.

Batteries shall not contain more than 0.0005 % mercury and 0.002 % of cadmium by weight. In case batteries contain more than 0.004 % lead, they should be marked with the chemical symbol for lead (Pb) in a well visible manner.

Cables shall not contain any polyvinylchloride (PVC).

The supplier is required to deliver proof over this criterion (e.g. by a valid RoHS certification/declaration and a declaration over the use of PVC-free cables).

3.4 Taking informed battery decisions

Table 3.4 What and why? Taking informed battery decisions

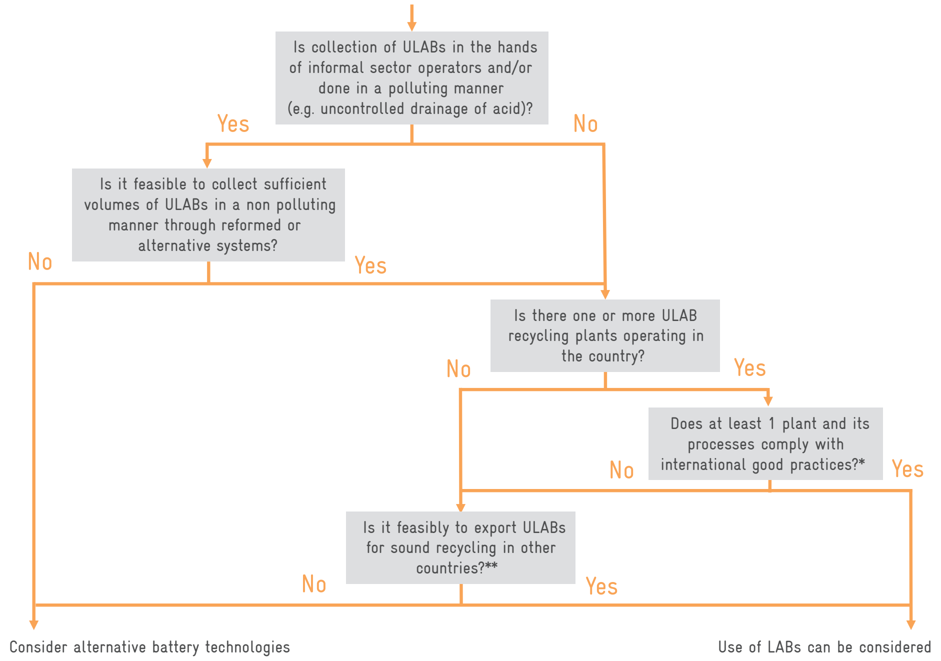
FAQ	Answer
What?	Batteries
Why?	The batteries are often the first components in off-grid electrification equipment that need replacement and their disposal is associated to substantial environmental, human health and safety (EHS) risks.
Context?	Early project stage / prior to any procurement decision: Lead-acid batteries can be chosen when a ULAB recycling plant that complies with international good practice is accessible or when the ULABs may be exported. The choice of Lithium-ion batteries may be more appropriate if a nearby recycling plant for ULIBs complies with international standards or if the ULIBs may be exported to other countries for sound recycling. The most appropriate battery type may be requested as part of the procurement criteria or as part of results-based financing (RBF).
Benefits?	The country-specific right choice of battery chemistries can significantly reduce EHS risks in end-of-life management.
Cost Implications?	Costs for screening (baseline assessment, see 4.1). The choice between ULABs or ULIBs (LFP) is currently similar in terms of costs. If extremely remote or conflict areas are supplied and alternative battery types such as saltwater batteries are chosen, the battery might be more expensive. Choosing LABs implies that the EoL management is cheaper than for ULIBs.

Source: Own compilation

Batteries deserve a high priority in EoL management of off-grid solar power installations: they are typically the first components that need replacement and improper recycling and disposal are associated to substantial EHS risks (see Table 2.1). The two most common battery types, LABs or LIBs, have substantial but very different challenges in terms of EoL management. The basic differences lay the type of EHS hazardous and the economics of recycling: While ULABs contain large amounts of hazardous lead and sulfuric acid, the material value (particularly from lead) motivates collection and recycling in most world regions. ULABs are hardly ever left behind and will find their way to recycling even in unregulated markets. The key challenge is that recycling practices are often highly polluting with severe impacts on human health of workers and neighbouring communities. In contrast, the toxicity potential of many LIBs is somehow lower, but batteries still contain various flammable and hazardous organic substances and metals, making sound management imperative. Furthermore, material values of LIBs are comparably low and even negative[9] with the LIB-types used in most off-grid installations (e.g. LFP batteries). Therefore, there is no direct economic incentive for collecting and recycling of LIBs, which means that many batteries will most likely not be collected in countries with insufficient mandatory requirements and related enforcement. Additional challenges are related to fire and explosion risks as old and damaged batteries with residual charge can overheat and burn / explode. This adds significant challenges to EoL management and is a serious challenge to waste management in general. Experiences from all around the world show that LIBs in the waste stream significantly increase the risks and frequency of fires during waste transport, handling, treatment and disposal (Herreras-Martínez, L., Anta, M., Bountis, R. 2021).

[9] Costs for sound end-of-life management is higher than potential revenues from material recovery.

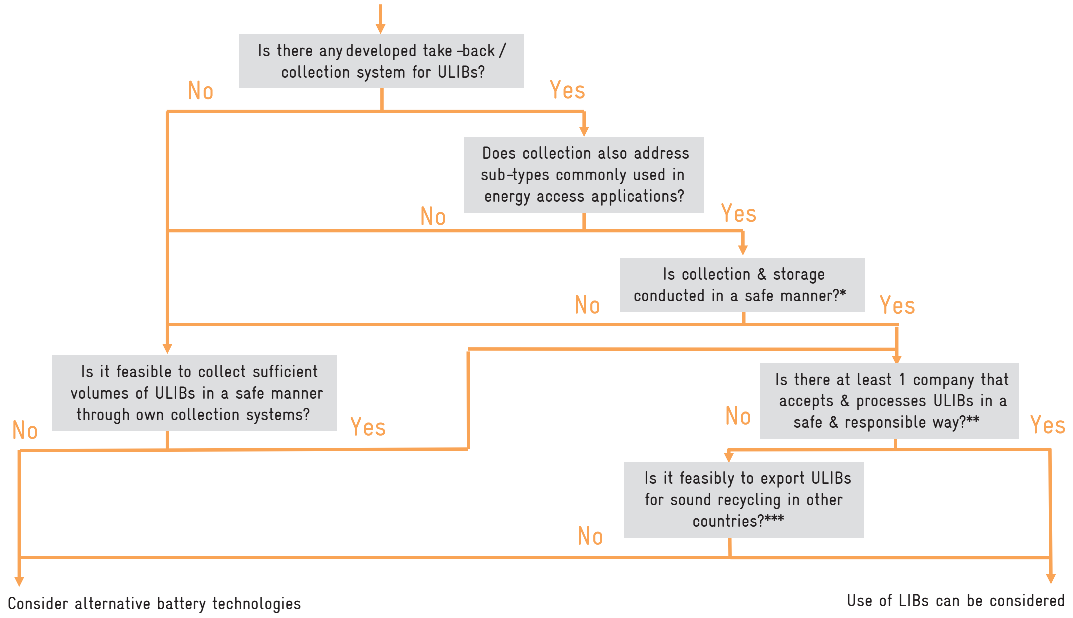
Figure 3.1 Decision-tree for or against deploying LABs in energy access projects



** Compliance can be verified through facility assessments/audits, using process guidelines such as the Standard Operating Procedures for Environmentally Sound Used-lead Acid Battery Management.*
*** Transboundary movements of ULABs require notification according to the procedures of the Basel Convention. Some countries limit exports of ULABs for the sake of protecting domestic recycling industries.*

Source: Öko-Institut e.V

Figure 3.2 Decision-tree for or against deploying LIBs in energy access projects



** Verification will most likely require assessment of collection & storage processes. Guidance on safety issues can be found at Herreras-M. et al. (2021)*
*** Safe processing includes testing and reuse, discharging, shredding, vacuum drying, sorting and possibly hydro- and/or pyrometallurgical treatment methods. EHS performance of processes is difficult to assess as reuse and recycling methods are still under development. Thus, assessments must either be based on self-assessments of companies, or on third party assessments.*
**** Transboundary movements of ULABs require notification according to the procedures of the Basel Convention. In addition, many shipping agencies are very reluctant of transporting ULIBs as such shipments have caused multiple fires of carriers in the past.*

Source: Öko-Institut e.V.

As a project or business manager, in order to determine whether to prefer or exclude a particular battery type, you need to ask yourself two main questions:

- Is it safe to assume that, under current conditions, ULABs and ULIBs are safely collected, recycled or finally safely disposed?
- If not: what can be done to achieve take-back and collection (within the country), safe recycling and disposal (within or outside the country)?

To find the answers, questions and decision-trees indicated in Figure 3.1 and Figure 3.2 can be used. While the figures give a rough guidance for decision-making, the underlying assessments might require further supporting measures such as a baseline study (see section 4.1) and facility assessments (see section 4.5).

In case the local situation speaks against both, the deployment of LABs and LIBs (e.g. extremely remote settings or high-risk areas and conflict zones) other battery types like saltwater (aqueous hybrid ion, AHI) batteries might be an appropriate alternative. The advantages of saltwater batteries are that they have essentially no fire or explosion risks, and contain less materials of concern (Graulich and Manhart 2017; Graulich et al. 2018). The disadvantage of AHI batteries is that they are typically bulkier due to their lower energy density compared to many other energy storage solutions (Graulich et al. 2018).

Batteries deserve a high priority in EoL management as they are the 1st components that need replacement.

How to get started »

Existing solar energy access projects »

- Leverage only if the project can still influence type of batteries in procurement / support funding. See next section.

For solar energy access projects in the programming phase »

- Collect information and literature on EoL battery management practices in your country of operation.
- Analyse existing EoL battery management patterns in your country of operation by applying the decision-trees of Figure 3.1 and Figure 3.2. Applying these methods will most likely require a baseline study (see section 4.1) and facility assessments (see section 4.6).
- Base decision-making of battery chemistry to be deployed in your project on the outcomes of this analysis.
- In case the local situation speaks against both battery types, consider steps around solutions pioneering as described in section 3.8.

Box 3.4 End-of-life battery management landscape in Uganda

Energy access through off-grid solutions is promoted and used widely in Uganda and is also supported through various donor agencies, including Energising Development (EnDev) Uganda and Energy Solution for Displacements Settings (ESDS) Uganda. Subsequently, the volumes of end-of-life batteries are projected to increase significantly in the next years. To develop a coherent strategy mitigating end-of-life related risks, EnDev and ESDS in close cooperation with the Ugandan Ministry of Energy and Mineral Development and GIZ commissioned a baseline assessment of the national e-waste landscape, including the assessment of existing formal recycling companies in the country. The facility assessments were carried-out between 16th and 19th of May 2022 and revealed a number of local activities around used and end-of-life batteries:

- There are two industrial recyclers for used lead-acid batteries operating in Uganda. Both recycle batteries to recover raw materials for own lead-acid battery productions in the country. One of the facilities has the main necessary up-to-date recycling equipment (modern rotary furnace and off-gas treatment system) and is located in an appropriate industrial zone. With some upgrades it can serve as a starting point for responsible battery recycling in Uganda.
- Some few solar companies already have a take-back system for end-of-life equipment, including batteries. Currently, ULABs are mainly given to the Lead Acid Battery Recycling Facilities mentioned above. Li-ion batteries are still stored as no feasible solution has been identified yet.
- There are various small players where used Li-ion batteries accumulate and some of them pilot the reuse of individual cells or modules in other products (e.g. for torch-lights, for power banks). Recycling of Li-ion batteries is not established in Uganda or anywhere else in East-Africa yet and will probably only kick-in once EoL battery volumes are higher and financing of environmentally sound management is assured.
- Transboundary movement of end-of-life batteries (e.g. shipment of EoL Li-ion batteries to recycling abroad) is difficult as there are very limited experiences with such shipments from Uganda that are in compliance with Basel Convention notification procedures.

In this situation, it is concluded that solar energy access projects may use both types of batteries (lead-acid and Li-ion), as long as they work on systems that make sure that:

- ULABs are channelled to the local lead-acid battery recycling facility using modern equipment, which is further supported in various aspects, including management of battery acid and smelting slags. Ideally, various energy-access providers, the government and the recycling company will commit to a constant improvement process targeting a high standard as laid down in respective standard operating procedures (Wilson and Manhart 2021).

Used Li-ion batteries are collected and channelled to players that can conduct testing and reuse under safe conditions (including product safety). Damaged batteries must be put in a safe storage system either awaiting future recycling or export to recycling. For this, training and support measures, e.g. incentivising collection, will be needed (e.g. for battery testing and safe reuse). In addition, solar companies and operators are called to develop/expand their take-back and collection systems for used equipment, including batteries to achieve the volumes needed for sound management and export of selected fractions.

3.5 Collection systems based on warranties and servicing structures

Table 3.5 What and why? Collection systems based on warranties and servicing structures

FAQ	Answer
What?	The repair and maintenance service staff regularly visits the beneficiaries of solar energy access installations. These logistic and service routines can be used to systematically collect faulty equipment. All parts of the solar energy access equipment are concerned.
Why?	Using existing logistic and servicing pathways, saves cost, increases customer contact and satisfaction and achieves a 'basic return flow' of obsolete equipment.
Context?	Early project stage / procurement: Ensure that a collection system is coupled with the warranty and servicing structure. Ongoing projects may engage into dialogues with the already contracted service providers to inquire about options for an extension of services to include collection. Important note: Collection does not need to be limited to the own equipment but shall include the faulty equipment of other projects and installations [10], too, to increase the equivalent amounts collected within the project period.
Cost Implications?	Collecting e-waste, even along established servicing structures, will incur costs. Reward servicing personnel (and possibly also consumers) for their additional work and expenses. Establish a differentiated compensation for different types of (solar) e-waste.

Source: Own compilation

One way to collect old or faulty solar energy access equipment is through a smart warranty and servicing structure: obsolete equipment is taken back, the customer experiences a good service and waste material is systematically collected. Setting up such a structure is an opportunity to take back similar waste material (e.g. TVs, radios, lamps, other batteries) from the served communities. To incentivize a broader collection, the take back of equipment and batteries may be accompanied by awareness raising measures and targeted incentives (e.g. mobile money payments, air-time credits) for obsolete equipment. Also, the service staff with the additional collection efforts must be rewarded by accounting for their additional working time and / or by paying them for the collected faulty items, with those who collect more receiving greater rewards. It makes sense to set different incentives for small devices (like solar lanterns) and larger devices or systems, to acknowledge the different collection effort as well as the value of the product. The incentive value may be determined by the raw material value but also by the ethical value of securing items with a particularly large EHS risk e.g. batteries (see also Section 3.3).

The 2018 WEEE Directive (WEEE Directive 2012/19/EU) describes categories of e-waste[11], whose characteristics imply different collection challenges. One category may for instance be particularly bulky, another category may contain a special type of hazardous substance. Complementary standards to the WEEE Directive exist (Nicholas et al. 2020), such as the norm EN 50625-2-4:2017 by the European Committee for Electrotechnical Standardization (CENELEC) for PV module collection and treatment, concretely describing the handling, sorting, transport and storage of the modules (>0.2m² surface area). Batteries are not covered under the WEEE directive, but good practices for the collection and transport of used batteries are outlined in the soon-to-be-published Standard Operating Procedures for Environmentally Sound

[10] The scope of collection must be clearly defined when including equivalent amounts. The 2018 EU WEEE Directive 2012/19/EU may provide ideas for categories of e-waste that may be distinguished, see Annex 1 for an earlier 10-category classification and Annex 3 for the current classification into six categories.

[11] Annex 3 of the 2018-WEEE directive lists the categories of (1) temperature exchange equipment, (2) screens, monitors and equipment containing screens (surface › 100 cm²), (3) lamps, (4) large equipment i.e. with any external dimension of more than 50cm (e.g. household appliances, IT equipment, toys, sports equipment, medical devices etc.), (5) small equipment i.e. with no external dimension larger than 50cm (same items as above, but smaller and excluding IT and telecommunication equipment) and (6) small IT and telecommunication equipment with no external dimension larger than 50cm.

Management of Used Lead-acid Batteries (Wilson and Manhart 2021).

Implementing a return flow of obsolete equipment through a servicing structure is a low hanging fruit to fulfil EPR obligations within the own field of project activities (also see section 2.2). Particularly suitable business models for implementing a collection system along with a servicing structure are leasing or lease-to-own contracts or Pay-as-you-Go (PAYG)-systems. These models typically entail repair and maintenance services regularly visiting users of solar energy access installations. These interfaces with users can be used to collect replaced and other obsolete equipment.

However, typically the collection volumes through a servicing structure are smaller than the volumes brought onto the market by the respective company or project. Thus, additional measures might need to be taken to achieve collection targets (as percentage of volumes brought onto the market (see also section 3.6).

In any case, it is important that collection, storage and transport is conducted in a safe way. So involved persons must be trained and equipped with appropriate collection containers and PPEs. Furthermore, storage facilities must be designed to prevent emissions and mitigate fire and other health and safety risks.

How to get started »

Existing solar energy access projects »

- Engage into dialogues with the already contracted service providers to inquire about options for an extension of services to include collection of EoL equipment.
- Choose activities from the list below as possible and appropriate.

For solar energy access projects in the programming phase »

- Ensure that warranties are given, that a service structure is in place and that a collection system is coupled with it.
- Collection does not need to be limited to the own equipment but shall include the faulty equipment of other projects and installations too. The objective is to increase the equivalent amounts collected within the project period.
- Clearly defined e-waste types to be collected / incentivised and which ones are not.
- Set transparent incentive schemes for (1) beneficiaries to let go of and hand in their equipment and for (2) servicing staff who will commit additional time and effort (logistics) for the collection. Different incentive types and amounts might have to be trialled for different contexts and types of e-waste to optimise return rates.
- Consider the additional costs for the demounting, transport, collection and temporary storage of faulty e-waste and batteries. Blair et al. (2021) report that the costs for setting up collection point ranged between US$20 and US$2000 in rural areas of various African countries, depending on their design and whether they were linked to existing infrastructure. Again: this demonstrates the large cost saving potential of adding collection activities to already established servicing structures.

Box 3.5 Examples of collection systems and incentive schemes

The 2021-Global LEAD Challenge report (Blair et al. 2021) describes the main lessons learnt in implementing solar e-waste management initiatives across Africa. The main insight concerning successful collection is that incentives were the main driving factor determining returned quantities. The involved off-grid solar companies paid on average US$ 1.17 for returned EoL solar products. Solibrium in Kenya paid on average US$ 34 since they focused on higher value solar home systems. Other companies offered vouchers for discounts on new products with the benefit of keeping customers and encouraging the purchase of quality and verified replacements. For instance, the company SunnyMoney in Zambia developed an incentivized voucher scheme, offering a 20% discount to customers returning faulty EoL products to their collection points. In Kenya, the Off-grid solar company d.light offered discounts on new solar lanterns in exchange for trade-ins of EoL solar products via their field agents and retail shops. They trialled a US$ 1 discount on their entry level lantern and a 50% rebate on a more expensive model, which both worked well, suggesting that consumers mostly cared about the total price of their replacement solar product. However, for d.light it was a challenge to motivate staff and agents since these were not receiving any benefit for collecting e-waste and thus prioritized other duties such as sales.

In Uganda, the off-grid solar company ENGIE Energy Access has developed a buy-back scheme for broken off-grid solar components of any brand as well as ULABs that were part of off-grid solar electrification equipment. The company reports that consumers in Uganda store as much as 20kg of e-waste at their homes, illustrating the potential and urgency for collecting equivalent amounts. The company trialled two buy-back prices for e-waste and found that a 16% price drop resulted into about 80% lower e-waste quantities collected. Through mapping out scrap collectors in Uganda the company concluded that sustainable e-waste management could be achieved through collaboration with industrial disposal companies that are able to handle large quantities of waste (Blair et al. 2021).

Consumers in Uganda store as much as 20kg of e-waste at their homes.

3.6 Collection and recycling through third parties

Table 3.6 What and why? Collection and recycling through third parties

FAQ	Answer
What?	All parts of the solar energy access equipment and/or equivalent amounts of e-waste shall be collected.
Why?	Not all solar e-waste can be collected through existing servicing structures as outlined in Section 3.5. Third parties may thus be commissioned to collect equivalent amounts of e-waste.
Context?	Early project stage/procurement: Ensure that collection of equivalent amounts of solar e-waste will be performed during the project period. Ongoing projects may calculate the volumes brought onto the market, set collection targets for equivalent amounts and contract third parties for the collection.
Cost Implications?	Owners of solar energy access equipment (beneficiaries) or informal e-waste collectors will only turn in or deliver e-waste to collection centres of third parties if the incentives are attractive enough. Commissioning third parties will have to cover their costs for the incentives, for further transportation, for storage and for organizing the logistics, see also Section 3.5. Depending on location and waste type, costs for collection are likely to range between 0.75 and 1.66 US$/kg (Magalini et al. 2020), but may be significantly higher for individual waste types such as end-of-life Li-ion batteries[12].

Source: Own compilation

As indicated in section 3.5, collection systems based on warranties and system serving might be insufficient to achieve ambitious collection targets (measured as percentage of volumes brought onto the market).

New or existing solar electrification projects may calculate the volumes they plan to bring onto the market, set collection targets for equivalent amounts and contract third parties for the collection. Collection through third parties is likely organized via collection centres or agents, where anyone (not only beneficiaries) may deliver their faulty equipment and receive a payment, voucher or other incentive in return, see also Box 3.5 in Section 3.5. Visiting individual households for picking-up e-waste without other service contracts i.e. without another source of income, will probably be too costly. Informal collectors may serve as middlemen, collecting larger quantities from individual households, organizing bulk transport and handing it over to collection points according to pre-defined criteria (e.g. no signs of burning/processing, use of safe transport and handling procedures). Attracting e-waste from the informal sector only works with sufficient financial incentives.

When contracting a third party for the collection, it is important to also define minimum health and safety standards for collection, storage and transport, see section 3.5.

Moreover, it is important to consider that collection is not the final step in sound solar e-waste management. The final step is the handing over of the e-waste to sound recycling, refurbishing or recycling enterprises, ideally in the region but possibly also abroad, see also Section 3.2. on recycling and recyclability of system components.

How to get started >>

No matter how small your first commissioned collection of equivalent amounts may be, the most important point is you start, showing your responsibility and commitment to tackle the emerging e-waste problem.

[12] Costs for treatment of EoL LFP batteries currently range between 2,000–3,000 €/t on the European market. This does not yet include costs for collection, handling and shipment.

Existing solar energy access projects »

- Engage into dialogues with the third-party service providers to inquire about the costs and possibilities for collecting equivalent amounts of (solar) e-waste.
- Engage with existing waste management projects waste management companies or collectors' associations and elaborate on potential co-operations for collecting (solar) e-waste.

For solar energy access projects in the programming phase »

- Commission the collection of faulty solar e-waste equipment, including those of other projects and installations. You may start small and set increasing targets based on the amount of equipment you brought and bring onto the market.
- Clearly define which e-waste types shall be collected and which ones should not, as well as the condition under which equipment is to be collected (e.g. no signs of burning / polluting processing; including hazardous components).
- Ask the service provider to set transparent incentive schemes for people and informal collectors to hand in their equipment or collected e-waste.
- Ask the service provider to train their staff at the collection centres to ensure a sound storage and transport (particularly relevant for EoL batteries).

Box 3.6 Collection of end-of-life Li-ion batteries through third parties

The Netherlands-based company Closing the Loop (CTL) work a business model that funds the collection and recycling of electronic waste in countries that lack appropriate take-back and recycling infrastructure. CTL's customers are organisations (e.g. companies, public sector institutions) that want to procure electronics in a greener way. These organisations pay CTL a compensation fee to make their purchases waste-neutral. These payments are used to fund the collection and environmentally sound recycling of a defined amount of e-waste. E.g. to make one purchased mobile phone waste-neutral, an end-of-life phone is collected and recycled, on behalf of the organisation.

For collection and recycling, CTL works with local recycling companies who again work with networks of agents for waste collection. The agents are trained in all relevant health and safety aspects and are provided with tools and PPE for conducting their tasks. In an effort to expand waste-neutral tech to computer screens and Li-ion batteries, CTL established a waste collection project in Nigeria in 2021. Here, the company was able to bring in 4,736 units of screens and 11 t of batteries within 14 months (Manhart et al. 2022; Schleicher et al. 2022).

In a similar manner, the GIZ E-waste Project in Ghana piloted an incentive-based collection system for end-of-life cables in Accra: Between March 2018 and August 2019, informal waste collectors and recyclers were given the opportunity to supply waste cables to a central handover centre, were they received a monetary compensation via mobile money transfer. The compensation was chosen in a way it exceeded the possible revenue from own crude recycling processes (open burning to liberate copper to be sold to traders). Subsequently, highly polluting cable burning was widely given up and most cables supplied to the system instead. In total, 27.5 t of cables were collected and passed on to sound recycling under the pilot (Manhart et al. 2020). The model is currently further developed and expanded under a KfW financed project implemented by the Ghanaian Ministry of Environment, Science, Technology and Innovation (MESTI).

3.7 Sector co-ordination

Table 3.7 What and why? Sector co-ordination

FAQ	Answer
What?	Team-up with other players of your sector (projects, programs), as well as neighbouring sectors (ICT, telecommunication) to create a larger market power for setting standards in procurement, establishing collection schemes or in pioneering solutions for improving local solar e-waste management.
Why?	Shared procurement criteria develop greater market power, shaping production (upstream) and facilitating EoL management (downstream). Developing a joint take-back scheme or jointly commissioning the collection of equivalent amounts decreases the unit costs for the participating projects or enterprises.
Context?	Sector-coordination can be initiated at any time, the earlier the better. Once established, the joint collection scheme or procurement criteria may be referred to for every new project being set up. Ongoing projects may serve for piloting of collection schemes and of pooling e-waste towards sound recyclers.
Cost Implications?	Sector co-ordination commonly enables synergies and significant cost reductions for implementing other measures described in this catalogue.

Source: Own compilation

Many of the measures described in this chapter can greatly benefit from synergies and co-ordination between various players in energy access efforts (donors, projects, solar companies…), as well as other players distributing and using e-products and batteries:

- Using common requirements for procurement (sections 3.1, 3.2, 3.3) yields higher market power, which will likely have positive effects on the availability of compliant equipment and their price. In an ideal scenario, sector coordination in procurement would widely push low standard equipment from the market.

- Sector co-ordination is also a very useful means to develop efficient collection systems (section 3.5 and 3.6). While such systems may be developed by individual projects alone, unit costs will decrease when various players joint forces and build-up collective take-back and collection systems. In that context, it should be stressed again, that implementing collection under the EPR-philosophy does not mean that each player should collect waste from own installations only. Using an approach based on equivalent amounts is much more efficient and enables such sector co-operation. In mature EPR systems, such co-operation is often a key success factor and termed 'Producer Responsibility Organisation (PRO)'[13].

- Solution pioneering is also a field where sector co-operation can be very useful (section 3.8). Either to co-fund / co-develop certain solutions, or to come to a meaningful division of tasks and foci: E.g. one project might pilot a collection system, while another develops a solution for EoL Li-ion batteries.

Sector coordination can also be very meaningful when it comes to choosing battery chemistries (see section 3.4) and managing EoL waste volumes. Sector co-ordination in pooling e-waste and EoL batteries for recycling and disposal contracts can have a strong pull effect on the local market: While high-standard recycling is often operating in a niche market or is even not developed at all, the possibility to be given priority access to large amounts of e-waste and batteries when applying high standards can stimulate investments in better processes and compliance.

[13] A PRO typically also takes over additional tasks, such as registration of producers and their product types and volumes, collection and management of EPR fees, organizing the recycling of collected waste and reporting to the authorities over collected and recycled waste types and volumes.

How to get started »

Existing solar energy access projects »

- Same as for new solar energy access projects (see below).

For solar energy access projects in the programming phase »

- Identify and contact other energy, energy efficiency or energy access projects and players in your country of operation, as well as ICT and telecommunications sectors and companies.
- Exchange with these players to find-out about their activities and strategies on equipment procurement and end-of-life management of energy access equipment.
- Identify potential synergies and fields of co-operation.
- Set-up a joint working group to work-out co-operation details and conduct implementation.

Box 3.7 Sector co-ordination for improving local battery recycling

End-of-life battery management in low- and middle-income countries is very often a key concern as recycling of used lead-acid batteries is often associated with severe pollution, while collection and recycling of Li-ion batteries is severely underdeveloped (Manhart et al. 2018). Solar energy access projects can influence the market by collecting their old batteries (or equivalent amounts of batteries) and tender them to recyclers that can prove to apply high standards. In case there is not yet any high standard recycler available, an MoU may be developed that describes an improvement path for the recycler and ties waste battery deliveries to the implementation of this plan.

Nevertheless, recyclers rely on economies of scale and the batteries supplied through individual projects are likely to be too small to justify investments in lasting facility and process improvements. In that situation, the combined market power of several projects (and probably also other battery holding sectors) can leverage influence. Ideally such an initiative is also linked to government efforts aiming to improve the national recycling landscape. Related ideas and approaches have been discussed within the Global Battery Alliance and found various interested partners, particularly in the African context (Angliviel et al. 2021). In Kenya, EnDev and the Global Association for the Off-Grid Solar Energy (GOGLA) also cooperate with a view to establish a coordinated collection and recycling approach for energy-access equipment in the country (EnDev 2022).

3.8 Solution pioneering

Table 3.8 What and why? Solution pioneering

FAQ	Answer
What?	Investment into third party e-waste management facilities, processes and capacities.
Why?	Where EoL management options are insufficiently developed, projects may actively engage in fostering the establishment of the required infrastructure i.e. collection and/or treatment (e.g. repair or recycling) facilities.
Context?	You may engage at any time into solution pioneering and support local businesses in support the setting up the required infrastructure and services.
Cost Implications?	Usually quite cost intensive. Examples: • Investments for processing of EoL Li-ion batteries indicatively range between 0,5 to 3 million Euro. • Piloting take-back and collection systems can be scaled, but still requires building up logistics.

Source: Own compilation

As indicated in section 2.3 responsible EoL management options might be insufficiently developed in some countries, so that a full implementation of the EPR philosophy as sketched in section 2.2 either requires exports for treatment in other countries, or application of 'second-best' solutions such as controlled hazardous waste disposal. In some cases, these options might be further limited by national legislation or company policies. A prominent example for such limitations is the management of EoL Li-ion batteries: While Li-ion batteries can be recycled, adequate facilities are all located either in Asia (e.g. Japan, China, S-Korea), Europe or N-America (Sojka et al. 2020), so that exports to such countries and facilities would be required. While such exports / shipments must be done in-line with the provisions of the Basel Convention, the battery related fire risks provide additional hurdles (see section 3.4). Due to various fire incidents on shipment carriers, most shipping agencies generally refuse to transport any end-of-life Li-ion batteries. In that situation, export to recycling is often not possible and requires local pre-processing / treatment, or local hazardous waste disposal[14].

In such situations, energy access projects can and should consider activities that support the development of feasible and sustainable solutions. In the case of EoL Li-ion batteries, this may constitute (co-)financing for setting-up local treatment facilities, and / or financing of local recycling pilots. In other settings, solution pioneering may also address unresolved collection issues, thus mainly focus on developing and piloting collection systems as precursor to larger permanent collection systems in a country.

As such solution pioneering is typically associated with high effects and costs (when put in relation to the volumes of collected / managed waste), a deviation from the "bring-one-in, take-one-out" approach (see section 2.2) is possible and justified.

In general, solution pioneering may greatly benefit from sector co-ordination (see section 3.7) and should ideally feed its results and lessons-learned into policy-development (see section 3.9).

[14] Disposal must clearly be regarded as less favourable option compared to recycling. In addition, the associated fire risks might raise questions regarding the type and modalities of disposal.

How to get started »

Existing solar energy access projects »

- Depending on the status of project (remaining time and funds), consider a reduced version of the sequence below.

For solar energy access projects in the programming phase »

- Conduct a baseline assessment to identify e-waste collection, reuse, recycling and disposal systems (see section 4.1).
- Use the baseline assessment results to check on existing management options for batteries and e-waste from your project; and identify potential gaps.
- In the case of gaps in collection: check if these gaps can be filled through measures described in section 3.5 and 3.6.
- In the case of other gaps (e.g. processing, recycling): Consult with stakeholders to identify alternative management options / solutions.
- Go into detailed planning on alternative management options / solution pioneering. This might include (but not limited to) consultation of sector experts (experts in logistics / recycling / hazardous waste management).
- Roll-out solution pioneering (potentially in cooperation with other players and stakeholders).
- Share results and lessons-learned with policymakers, other projects and initiatives, and the wider public.

Box 3.8 Pioneering end-of-life management of Li-ion batteries in Nigeria

Full environmentally sound solutions for end-of-life Li-ion batteries are still absent in most African countries. Nevertheless, end-of-life volumes are expected to increase rapidly. In this situation, the Nigerian recycler Hinckley started to explore options for used Li-ion batteries in 2019. These activities led to a first controlled export of end-of-life Li-ion batteries for recycling in cooperation with the company Closing-the-Loop in 2020 (Closing the Loop 2020). In parallel, Hinckley developed testing of collected batteries to identify functional cells suitable for local reuse and repurposing activities.

In a recently announced cooperation, the solar company Lumos teamed-up with Hinckley to support setting-up processing of end-of-life Li-ion batteries locally in Nigeria (Olowookere 20 Mar 2021).

3.9 Policy support

Table 3.9 What and why? Policy support

FAQ	Answer
What?	Support the development of policies e.g. towards the establishment of an EPR scheme, or the establishment and enforcement of minimum standards.
Why?	An effective policy framework that fosters the sound management of e-waste and end-of-life batteries supports the creation of level playing field for market players, including energy access system providers and electrification projects. Setting and enforcing national standards can have a similar effect. In both contexts, implementation and enforcement are key preconditions for success.
Context?	You should only consider engaging into policy support when all of the following criteria are fulfilled: • There is an active demand from authorities in charge for management of e-waste and EoL batteries (e.g. Ministry of Environment). • There is no other cooperation project giving such policy support, or this other project agrees to coordinate / share efforts / use synergies. • You have enough time and resources to conduct policy development over a period of at least 2-3 years. • National agencies (e.g. agency responsible for the environment) are capable and willing to enforce developed policies.
Cost Implications?	High. Meaningful policy support measures require stamina and support over prolonged time periods.

Source: Own compilation

Policy support with the aim of developing national policies, regulations and EPR-based financing systems is a possible intervention measure for projects that closely operate with national governments. Engaging into policy support makes sense where there are insufficient policies and regulations and / or where EPR is not yet implemented. It should be noted, however, that policy support in this field usually takes a long time. Experience shows that the process of policy development from the start to the establishment of an EPR system usually takes several years.

Targeted but individual interventions, e.g. workshops without follow-up support, often do not provide the necessary and tangible added value. Moreover, a cacophony in policy advice must be avoided, i.e. it is important that different actors coordinate, agree and speak with one voice to make clear policy recommendations. Furthermore, there should be an active demand (interest) on the part of partners for such support. It should be noted that waste management issues are mostly dealt with by the Ministry of Environment, whereas energy access projects, in many cases, cooperate mainly with government agencies that are responsible for energy supply and rural development.

Policy support should not be the only measure a project takes. The "lead-by-example" approach (i.e. the implementation of other measures from Chapter 3) provides a higher level of credibility as well as good-practice examples that can be referred to during the policy support process.

How to get started »

Existing solar energy access projects »

- Only consider engaging if you have enough resources and at least 2-3 years project time left. If this is the case, follow steps for 'new solar energy access projects'.

For solar energy access projects in the programming phase »

- Familiarise yourself with the existing legislative framework for e-waste and EoL batteries (e.g. in the context of a baseline assessment, see section 4.1).
- In case there are gaps in legislative frameworks and implementation, get in an exchange with relevant policy-makers to elaborate potentially planned steps / initiatives.
- In case there is an active support request from relevant policy makers, check carefully if this request can be satisfied through your project and if there are no other players capable and willing to give related support.
- If you decide for policy-support, start a close dialogue process with policy makers and key stakeholders. The process should first clarify the following key points:
  - Objective of the initiative (e.g. reducing pollution, generation of jobs…)
  - Scope of the policy-development (e.g. collection and recycling of e-waste / hazardous waste / minimum product standards)
  - Links to other regulatory initiatives
  - Key stakeholders to be included in the process (also see section 4.2)
  - Responsibility for the policy-development process (usually by a national ministry)
  - Collection of policy-options to achieve the objectives
  - Know-how transfer and open stakeholder exchange to allow informed decision-making on policy options
- Support the policy process with concrete piloting activities (e.g. measure 3.5 collection of solar energy access equipment).

Box 3.9 Policy development on lead-acid battery management in Ethiopia

The environmental and health problems caused by unsound management of used lead-acid batteries was brought to the attention of governments through a number of case studies, including in Ethiopia (Manhart et al. 2016). The Ethiopian government took these findings seriously and used its cooperation with EnDev and a broad range of further stakeholders to agree on a roadmap for improved life-cycle management of batteries in 2019.

While the country already had a Hazardous Waste Management and Disposal Proclamation (Proclamation 1090/2018) setting out the conditions for hazardous waste management, additional specific guidance for lead-acid batteries was needed; including for producers, importers, users, collectors and recyclers. In this context, EnDev supported the development of a Directive for Environmentally Sound Management of Lead-acid Batteries, as well as a set of technical guidance documents for all involved industry players. While the material is about to be adopted by the authorities, its implementation will require pro-active players and networks that improve processes and engage in the collection and sound end-of-life management based on the principle of Extended Producer Responsibility (EPR). In that context, EPA and EnDev are interacting with key stakeholders from the solar sector, battery collection and recycling and set-up a 'group of pioneers' that takes first practical actions towards Extended Producer Responsibility. In parallel, EnDev supports EPA in drafting legal EPR requirements in this field.

4 Further supporting measures

The following sections describe supporting measures that may be planned and conducted in support of a wider improvement strategy and one or more measures described in chapter 3. The supporting measures of this chapter likely have a very limited lasting positive impact when conducted as standalone, but may be decisive stepping-stones for achieving positive impacts through one or more measures described in chapter 3.

4.1 Baseline assessments

When getting familiar with the e-waste and waste battery management situation in a country, baseline assessments are very often a very useful means to compile relevant information and develop starting points for measures such as those presented in chapter 3. Table 4.1 gives an overview on subjects, topics, guiding questions and information sources for conducting full comprehensive baseline assessments.

When conducting such baseline studies, it is important to consider availability of resources for both, the baseline assessment, as well as potential subsequent measures. In general, it is recommended to scale the effort for baseline assessment so that it does not consume more than 20% of the available budget for EoL management. In any case, baseline assessments should start with collection and review of existing literature, as e-waste focused studies are available for various countries and regions. In addition, it might be possible to join forces with other projects and initiatives with similar aims and targets.

E-waste focused studies are available for various countries and regions.

Table 4.1 Subjects, topics, guiding questions and information sources for baseline assessments for e-waste and EoL battery management

Subject	Topics & guiding questions	Information sources
E-waste volume	Annual generation of e-waste	(Forti et al. 2020)
	Per capita generation of e-waste	(Forti et al. 2020)
	Differences between urban and rural areas (qualitative)	Various
	Development of waste generation from off-grid electrification	Sector studies
Regulatory framework	Has the country signed/ratified the Basel Convention?	(Basel Convention, 2019)
	Are there laws/regulations on e-waste and Extended Producer Responsibility?	(Forti et al. 2020)
	If yes, what are the core elements and requirements for producers, importers, users, collectors and recyclers?	National laws & regulations
	How do these requirements affect the conduct of solar energy access projects?	National laws & regulations
	How are laws and regulations enforced?	Interviews
E-waste collection	Is there any officially approved collection and take back system for e-waste or parts thereof?	Field studies, interviews
	If yes, how effective (volumes, regional coverage, e-waste types) is this type of collection?	Field studies, interviews
	Are informal sector operators engaged in e-waste and waste battery collection and recycling?	Field studies, interviews
	If yes, what is their primary focus of activities?	Field studies, interviews
	Are there collection systems/networks that can be utilised for collection of used and EoL solar equipment?	Field studies, interviews
Reuse	Are there companies focusing on high quality repair and reuse operating in the country? Can they serve as partners for equipment repair and maintenance? Are there repair associations?	Internet, field studies, interviews
Recycling	Are there registered e-waste recycling companies in the country?	Internet, field studies, interviews
	If yes, what is their field of activities (depollution, dismantling/pre-processing, end-processing, types of equipment…)	Internet, field studies, interviews, facility assessments
	What is known about the EHS performance of these companies?	Facility assessments, audit reports, environmental authorities
	Are there any battery recycling companies operating in the country (e.g. ULAB recycling/secondary lead smelters)?	Internet, field studies, environmental authorities
	What is known about the EHS performance of these companies?	Facility assessments, audit reports, environmental authorities
Hazardous waste disposal	Are there any licences hazardous waste treatment & disposal facilities in the country?	Environmental authorities
	Is it possible to export selected e-waste types and EoL batteries to other countries for treatment/disposal?	Basel Convention focal point (typically part of a national environment agency)

Source: Own compilation

4.2 Stakeholder workshops

Consultation with stakeholders is a key means to collect various perspectives on issues such as e-waste collection and recycling, and to get a sound understanding of potential measures. In that context, stakeholder workshops are often used to support analytical steps (as those required for baseline assessments), for raising awareness (e.g. on the importance of sound e-waste and waste-battery management), and for strengthen dialogue between various players.

In most settings, stakeholder workshops are likely to be an indispensable element for planning and conducting measures. On the other side, stakeholder workshops shall never be seen as a standalone activity: Participants of such workshops invest their time and provide their knowledge and experience, so that they rightly expect follow-up activities that effectively serve the intended purpose – in this case, the improved management of e-waste and waste batteries from energy access installations. Thus, stakeholder workshops must be well embedded in activities leading to the implementation of one or more measures described in chapter 3. Table 4.2 gives an overview of major stakeholder groups that are often relevant for managing e-waste and waste batteries from energy access applications.

Stakeholder workshops shall never be seen as a standalone activity.

Table 4.2 **Major stakeholder groups relevant for e-waste and waste battery issues**

Stakeholder group	Sub-group	Description
Government policy makers	Environmental policies	Ministry responsible for environment. Some countries have no ministry for environment. There, environmental agency commonly takes over policy tasks
	Energy policies	Ministry responsible for energy
	Industry policies	Ministry responsible for industries (Maybe relevant in settings where new recycling capacities are required)
	Trade policies	Ministries responsible for trade (Maybe required in settings where exports of waste and commodities are tightly regulated)
Inspection & enforcement	Environmental agencies	Typical in charge of enforcement of policies, including licensing and inspection of recycling and waste disposal facilities
	Factory inspectorate	In most countries aspects around health & safety are enforced through an own agency
	Third party auditors	In some countries, inspection tasks are conducted by third party auditors (typically private companies registered with the environmental agency and/or factory inspectorate)
	Possibly also authorities in charge of import regulations (e.g. customs) and product related standards	These organisations are needed for holistic EPR systems which are based on a register of parties bringing equipment onto the national market, and for introducing and enforcing minimum (environmental) standards for products.
Waste management sector	Waste collectors (formal)	Companies primarily focusing on the collection and managing of municipal solid waste
	Waste collectors (informal)	Informal networks (often referred to as 'scrap collectors' or 'scavengers') focusing on collection of value containing wastes (e.g. metals)
	E-waste recyclers (formal)	Companies focusing on the treatment, dismantling and depollution of e-waste.
	E-waste recyclers (informal)	Informal networks conducting dismantling and crude processing of e-waste and/or batteries.
	Repair sector	Companies focusing on repair and refurbishing of used electrical and electronic equipment
	Scrap dealers	Companies focusing on the trade of scrap metals (copper, aluminium, PCBs…) and who often represent a link between local recycling (formal and informal) and shipment of scraps to foreign destinations
	ULAB recyclers	ULAB recycling is a specific sector requiring processes that are very different from e-waste recycling.
Solar system providers	Equipment importers	Players that import systems and components thereof
	Off-grid solar companies	Companies that are active in supplying, installing solar off-grid systems
	Serving & maintenance	Companies focusing on serving, maintenance and repairs of solar systems
Science	University & non-university institutes	Scientist focusing on topics related to e-waste/batteries/pollution prevention/waste management
Civil society	Civil society groups	Civil society groups on topics related to e-waste/batteries/pollution prevention/waste management

Source: Own compilation

4.3 Awareness raising

Awareness for the potentially adverse effects of e-waste and EoL batteries is an important precondition for many improvement strategies in this field. In many cases, people and organisations only act on this issue, once they understand the importance and consequences of right / wrong behaviour. This aspect applies to behaviour on an individual and household level (how to dispose of waste), as well as to the level of solar companies, policy makers and other stakeholders.

Nevertheless, awareness raising has severe limitations when conducted as standalone activity. Because improvements do not only rely on people and organizations understanding the problem, but also on the availability and accessibility of solutions. If people are made aware of the problems of unsound disposal of e-waste and batteries, they can only translate this into action if they are given clear guidance and solutions on what to do (e.g. on how to dispose e-waste).

In that context, it must be clearly differentiated between

1. awareness raising amongst policy makers and private sector stakeholders
2. awareness raising amongst the general population.

While No. 1 is often an indispensable precondition for developing measures of chapter 3, No. 2 is usually associated with significant efforts and must be carefully planned. In that context, planning should consider the following questions:

- What should be achieved by awareness raising activities?
- Who is the target group and what are the main messages?
- What are suitable locations and occasions for awareness raising? e.g. at the point of sale of solar equipment?
- What solutions can be communicated and promoted so that increased awareness leads to improved e-waste management?
- Are there alternative means to achieve comparable (or even better) results?

The latter aspect may apply in situations where awareness raising is considered for the aim of increasing collection rates for e-waste and waste batteries. Here alternatives may involve monetary or non-monetary incentives for handing over e-waste and batteries. While such incentives often appear to be very costly, the effectiveness of awareness-based collection should not be overestimated, and costs for awareness raising activities not underestimated[15].

[15] Collection strategies exclusively based on awareness of consumers and households are usually limited in terms of collection rates (because only a certain share of consumers will act on the base of given information). In addition, collection rates are likely to deteriorate over time if no repeated or ongoing awareness raising is conducted.

4.4 Working with informal sector operators

Informal sector operators are in many countries a key feature of existing e-waste collection and recycling pathways. Most informal activities are poverty driven by a lack of formal employment opportunities with better payment and working conditions. Thus, the existence of informal waste and scrap metal sectors are inherently linked to the socio-economic situation of societies and countries. Informal e-waste collectors and recyclers typically focus on collection and sale of scrap metals with a positive market value. Therefore, informal players are not interested in all types of e-waste, but in devices and components that contain steel, aluminium, copper, brass, lead and printed circuit boards (PCBs)[16]. Therefore, most informal players do not exclusively focus on e-waste, but on all scrap types that contain at least one of the metals indicated above.

Sometimes, informal networks are also linked to reuse and repair activities, either by picking-up metal containing waste from repair workshops, or by suppling selected goods to repairers (e.g. to be used as source of spare parts).

Informal e-waste collection and recycling is often considered a major environmental and social hot spot, which is mostly due to the following factors:

- Because of the exclusive focus on valuable materials, informal sector operators often conduct own dismantling and processing activities. Non-valuable materials (that often contain pollutants) are commonly discarded uncontrolled or even burned to reduce waste volumes.
- Informal operators sometimes use crude and polluting practices to liberate metals. The most prominent and common example is the open burning of cables and other components to recover copper. Such open cable fires are a major source of pollution and emit substantial amounts of dioxins and furans.
- Informal sector operators often also collect lead-acid batteries and partly conduct own dismantling operations, mostly uncontrolled acid drainage and breaking and dismantling of batteries. Both practices are associated with substantial pollution of the local environment.
- Working conditions are often precarious and applied processes partly dangerous and conducted without sufficient safeguards[17].

[16] Printed circuit boards of electronic equipment (including the mounted parts and the solder paste) contain a large variety of elements, including copper and traces of precious metals. These metals can be recovered with a profit in industrial recycling and refining processes, which is the main driver behind collection and trade of these boards worldwide.

[17] Child labour has not been found to be a dominant feature in informal e-waste collection and recycling. But children are often present in and close to informal e-waste recycling clusters and sometimes conduct lighter work such as sorting of smaller scrap types.

All these activities can be attributed to cost-externalisation: While alternative safer and less polluting solutions exist, they are associated with higher costs and are therefore unattractive for most players. As scrap metal collection and recycling is a highly competitive business, players applying less polluting (but more costly) processes risk getting marginalized and deprived of scrap metal flows.

But scrap metal collection and trade also have positive effects, including the generation of income, the recovery of raw materials and reduction of waste volumes. In addition, informal collectors are often a convenient way for households to dispose-off bulky waste types.

In that context, support and upgrading of informal sector collectors and recyclers may appear to be a meaningful way to improve e-waste management in a defined geographic location. While there are positive examples of sector upgrade and formalization, related support requires time, resources and is dependent on various other framework conditions including a supporting political agenda, clarification of property and land-use rights and registration / formalization processes.

It must also be considered that informal sectors are often large and manifold and that isolated support-measures such as the erection of workshops may benefit some individuals, while not changing the underlying dynamics of cost externalisation.

Therefore, working with informal sectors must be planned carefully and based on realistic assumptions and expectations. One meaningful way of integrating informal sector operators is in collection activities, where informal collectors are encouraged / mandated to collect and supply defined e-waste and battery types and by applying fair compensation structures, training and further support measures (see sections 3.5 and 3.6).

Scrap metal collection and recycling is a highly competitive business.

4.5 Capacity building of competent authorities

Every government system has authorities that are responsible for licensing industrial activities, and to monitor environmental performance and workplace safety. These procedures shall ensure that only companies are allowed to operate that implement effective environmental, health and safety measures. The relevant authorities are not only involved in licensing but can also demand access to any facility at any time to conduct inspections[18]. Based on inspection outcomes, facilities can be requested to implement improvement measures. If such measures are not taken, companies may be fined or even closed by the authorities.

Although this licensing and control system has strong limitations in informal sector settings[19], it can be very effective in market segments that are mainly characterised by formal sector operators. This is particularly the case for lead-acid battery recycling where industry-scale facilities increasingly take over recycling operations from informal sectors[20]. In such segments, government oversight and control must be thorough in order to avoid sub-standard processes and to stimulate investments in upgrades for environmental performance, safety and industrial hygiene.

While environmental authorities are commonly willing to play an active role in this field, they often face various challenges:

- There is often a strong political lobbying not to put any burden on private industries so to enable investments and generation of jobs. Formulation and enforcement of environmental minimum standards are sometimes seen in such a context.
- Many regulatory authorities are responsible for monitoring a wide range of industrial and commercial activities and do not have up-to-date expertise on all involved processes.

In that context, a training of inspectors can help to provide up-to-date know-how and tools for their licensing and inspection duties and can also give them a sound understanding of economic implications of minimum standards[21]. Training may use a combination of theoretical and practical activities, possibly linked to facility assessments (see section 4.6) and training of plant managers.

Training may also be required for the competent authority in charge of setting and enforcing product related minimum standards (e.g. repairability, RoHS, Verasol amongst others) and implementation of the prior-informed consent procedure (PIC-notification) for the transboundary movement of hazardous waste as regulated through the Basel Convention. While the latter procedure is an important tool to limit the illegal imports of hazardous waste (including e-waste), it is also a critical aspect in cases where e-waste or fractions thereof must be shipped to foreign destinations for further processing. A lack of administrative know-how and processes can be a severe hurdle for such processes and represent an unnecessary burden to formal e-waste recycling in a country (PREVENT Waste Alliance 2022).

[18] Depending on the country, military complexes and industries may be excluded from this.

[19] By definition, informal sector players are not registered with the authorities and operate under their radar. Attempts to control and regulate informal sector recycling is often subject to severe difficulties as a) informal sector operators a) are large in number, b) tend to avoid registration, and c) can flexibly relocate activities to avoid regulatory pressure.

[20] Informal ULAB recycling has very low lead recovery rates of only 50-60%. With investments into industry-scale smelting facilities, recovery rates can be increased to > 90%. Due to this efficiency gain, formal sector recycling is progressively replacing small scale informal ULAB recycling in many countries, even without related policy initiatives. Nevertheless, industry-scale ULAB recycling in formal plants can also be subject to sub-standard conduct, severe pollution and unsafe working conditions (Wilson and Manhart 2021).

[21] In most cases, enforcement of environmental minimum standards does not cause job losses or reduced investor interests as long as all players of a sectors have to stick to the same set of rules and benchmarks. In turn, environmental minimum standards are often a pre-condition for many responsible operators to invest in a certain jurisdiction.

4.6 Facility assessments

Decisions on battery chemistry choices (see section 3.4), measures on collection and recycling (see sections 3.5 and 3.6) and solution pioneering (see section 3.8) require a thorough understanding of the EHS performance of potential recycling partners. This is important because e-waste and end-of-life batteries may not only be miss-managed by informal sector operators, but also by some formal recyclers. It is therefore important to get an impression on the EHS performance of companies before entering contractual relationships. This may be done by the following means:

- Contact the company and request a copy of the environmental license issued by the competent authority.
- Contact the company and request certificates and auditing reports of third parties.22
- Conduct own facility assessments (with allowance of the company).

Table 4.3 gives an overview on common standards and certification systems relevant for e-waste and battery recycling. Coverage of these standards / certification systems in low- and middle-income countries is often insufficient, so that additional facility assessments might be necessary.

Facility assessments should be done by trained and experienced auditors and ideally with a method or standard listed in Table 4.3. With regards to e-waste pre-processing, it is also important to check on the whereabouts of output fractions, and not only the processes and housekeeping within a plant. This is because the management of (hazardous) output fractions is often one of the main points of concern: A plant might be managed according to a high standard, but inappropriate disposal of hazardous outputs might still create severe environmental problems.

Facility assessments are usually documented in assessment or auditing reports. These reports should describe and summarize all findings of the assessment and make suggestions for facility improvements. Depending on the scope of the assessment, the auditors might also be asked to make a general recommendation for cooperation (e.g. recommended for cooperation, not recommended for cooperation, recommended under condition of improvement).

It is important that the facility cooperates with the auditors. Thus, the scope of the assessment should be made transparent, and an agreement over the use of the auditing results / report must be met before the start of the assessment[23]. The assessment should be made when the facility is in full operation.

[22] Licenses, certificates and auditing reports are usually site/facility specific. Therefore, it must be checked if the provided material does cover all facilities and operations to be used in the envisaged partnership.

[23] Usually, the agreement entails that the full assessment report is only given to the client (assessing entity) and the company (assessed entity). Furthermore, only the company (assessed entity) may pass-on the report to third parties. Other agreements on assessment summaries may be arranged.

Table 4.3 Common standards and certification systems for e-waste and battery recycling

Name	Scope	Description
WEEELABEX	E-waste pre-processing/recycling	Certification system for e-waste recyclers based on the CENELEC 50625 serries
E-Steward	E-waste pre-processing/recycling	Standard by the NGO Basel Action Network
CENELEC 50625-1	General treatment requirements of e-waste	Requirements for collection, logistics & treatment of e-waste. Further specifications in TS 50625-3-1
CENELEC 50625-2-1	Recycling of lamps	Requirements for recycling of lamps. Further specifications in TS 50625-3-2
CENELEC 50625-2-2	Recycling of displays	Requirements for recycling of displays. Further specifications in TS 50625-3-3
CENELEC 50625-2-3	Recycling of temperature exchange equipment (fridges & air conditioners)	Requirements for recycling of refrigerators & air-conditioners. Further specifications in TS 50625-3-4
CENELEC 50625-2-4	Recycling of photovoltaic panels	Requirements for recycling of PV panels. Further specifications in TS 50625-3-5
Benchmark Assessment Tool for ULAB recyclers	Recycling of used lead-acid batteries	Tool to assess EHS performance of ULAB recyclers by the International Lead Association. No guidance document available
ISO 14001	All industrial plants	Certification of environmental management system (incl. continuous improvement). Not specific to e-waste and battery recycling

Source: Own compilation

Source: Own compilation

4.7 Investment promotion

As indicated in section 2.3 and 3.8, EoL management might be insufficiently developed in some countries with significant investment needs in collection systems and management and recycling infrastructure. Support in terms of identifying and contacting potential investors for these tasks may under some circumstances help to fill this gap. To do so, the following issues should be considered:

- In most aspects of waste management, operational costs (OPEX) are quite high. Therefore, taking-over of investment costs (CAPEX) does not necessarily mean that management and recycling solutions will kick-in and be sustained automatically. Without solid financing mechanism for operational costs, investments in facilities are likely to be unsustainable.

- This is actually a major reason why investments in full responsible collection and recycling of e-waste and end-of-life batteries are still very limited in many countries: As long as other players base their business model on externalization of costs (see section 2.4), competition from polluting recycling is too strong to justify investments in responsible operations.

Therefore, investment decisions in high standard recycling often resemble chicken-and-egg situations: As long as there is no, or very limited demand for full environmentally sound solutions (which are associated with higher operational costs, compared to rude recycling), interests of investors in financing responsible solution is likely to be limited. And as long as there are no readily available solutions for sound end-of-life management available, many players (e.g. energy-access projects) feel overwhelmed with identifying and developing solutions.

Therefore, attempts to promote investments should consider benefits in terms of access to waste and coverage of operational costs: In case investors can count on defined minimum volumes of e-waste and EoL batteries, as well as fair compensation conditions covering the costs for environmentally sound management, the interest of potential investors is likely to increase. Therefore, sector co-ordination and pooling of waste (see section 3.7) is a meaningful way of supporting a favourable investment climate for investments in e-waste and EoL battery management and recycling.

In addition, specific funding mechanisms may be used to support investments. The Global LEAP Solar E-Waste Challenge in 2019 provided USD 1.1 million to companies with innovative approaches to e-waste management in the off-grid solar sector in sub-Saharan Africa (Efficieny for Access 2021). The focus was on pilots or early-stage projects that focused on data gaps, logistical challenges and operational access. The competition received 159 nominations out of which eight winners in five countries are working on further improving e-waste management.

5 Literature / further reading

The following references are considered useful material for planning measures around e-waste and EoL battery management in solar energy access projects.

Table 5.1 Overview of useful publications for further reading

Title	Type of publication	Content	Reference
Global e-waste monitor	Website & report	Country data on generated e-waste volumes, per capita generation, collected volumes and existence of e-waste legislation. Publication is regularly updated.	(Forti et al. 2020)
International e-Waste Management Practice	Report	Factsheets for 12 countries covering aspects around e-waste legislation, collection and recycling systems, financing mechanisms, targets, reporting & monitoring.	(Khetriwal and Jain 2021)
End-of-Life Management of Batteries in the Off-Grid Solar Sector	Report	Overview on issues around end-of-life issues of batteries used in energy access projects.	(Manhart et al. 2018)
E-waste Training Manual	Report	Overview on pre-processing and end-processing pathways of major e-waste types, including health & safety and pollution aspects	(Lenz et al. 2019)
Dismantling Guide for IT-equipment	Report	Description of dismantling/pre-processing steps for IT-equipment. Also available in Spanish.	(Blaser et al. 2015)
Packaging Lead-acid Batteries for Bulk Transports	Poster guide	Picture illustrated step-by-step guide to safely pack and ship used lead-acid batteries. Also available in French, Arabic, Hausa and Twi.	(Öko-Institut, City Waste Recycling, Johnson Controls 2015)
Standard Operating Procedures for Environmentally Sound Management of Used Lead-acid Batteries	Report, Standard Operating Procedures	Picture illustrated guideline document on all steps of the ULAB management chain.	(Wilson and Manhart 2021)
Management of End-of-life Li-ion Batteries through E-waste Compensation in Nigeria	Report	Description of technical options and economic framework conditions for setting-up Li-ion battery recycling in Nigeria. Much of the content is transferable to many other countries)	(Manhart et al. 2022)
Innovations and Lessons in Solar E-Waste Management (Global LEAP Solar E-Waste Challenge)	Report	Lessons learnt about design and implementation of solar e-waste management from eight Challenge projects across Africa	(Blair et al. 2021)
Processing of WEEE plastics	Report/ handbook	Good overview on technical sorting and processing options for plastic from e-waste. Also available in Spanish and Albanian.	(Bill et al. 2019)
EPR Toolbox	Interactive online tool & report	Background and elements on legal and organisational aspects of mandatory EPR systems. Although focusing on packaging waste, much of the content can also be applied for e-waste related policy support measures.	(Bünemann et al. 2020)
E-waste policy handbook	Report	Comprehensive overview on various aspects around e-waste policies and EPR	(Magalini et al. 2019)
Policy practices for e-waste management – Tools for fair and economically viable extended producer responsibility	Report & case studies	Quick start guide on e-waste related EPR systems with checklists and some country case studies from Africa.	(ITU 2021)
Practical Experiences with the Basel Convention: Challenges, Good Practice and Ways to Improve Transboundary Movements of E-Waste in Low and Middle Income countries	Discussion paper	Lay-out of challenges and solutions related to the implementation of the Basel Convention for e-waste exports from low- and middle-income countries	(PREVENT Waste Alliance 2022)

Source: Own compilation

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List of abbreviations

ABS	Acrylonitrile-butadiene-styrene
AHI	Aqueous Hybrid Ion
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CdTe	Cadmium Telluride
CSI	Crystalline Silicon
EEE	Electrical and Electronic Equipment
EHS	Environment, Health and Safety
EnDev	Energising Development
EoL	End-of-Life
EPR	Extended Producer Responsibility
EU	European Union
GOGLA	Global Off-Grid Lighting Association
LABs	Lead-acid Batteries
LFP	Lithium-iron phosphate
LIBs	Lithium-ion Batteries
LME	London Metal Exchange
PAGO	Pay-As-You-Go
PCB	Printed Circuit Board
PIC	Prior Informed Consent
PPE	Personal Protective Equipment
PRO	Producer Responsibility Organization
PV	Photovoltaic
PVC	Polyvinylchloride
RoHS	Restriction of Hazardous Substances
SDG	Sustainable Development Goal
SHS	Solar Home System
UNBS	Uganda National Bureau of Standards
ULABs	Used Lead-acid Batteries
WEEE	Waste Electrical and Electronic Equipment

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