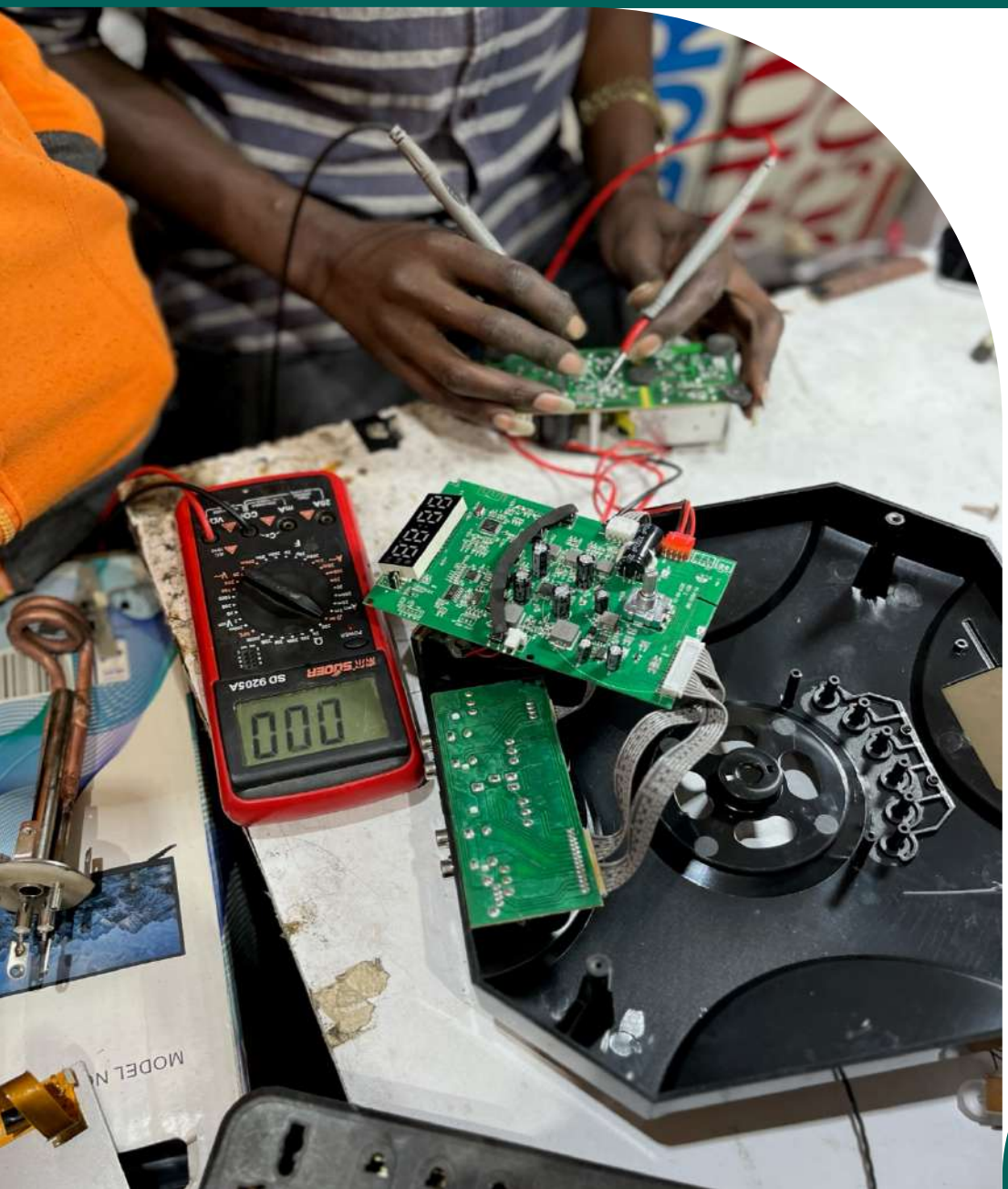
EFFICIENCY FOR ACCESS

CLOSING THE LOOP:

ENHANCING REPAIRABILITY IN THE SOLAR APPLIANCE MARKET



October 2024

Efficiency for Access Coalition

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Context & Acknowledgements

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Executive Overview

Solar appliances often constitute a significant financial investment, especially for those living in off-grid regions in Africa where recycling is also limited. Enhancing appliance repairability aims to protect consumer investment and the environment by incentivising designs that are easier to repair or refurbish.

Field research in Kenya and interviews with 32 stakeholders revealed that the repair of solar appliances is currently managed in an informal, uncoordinated way. This poses challenges to the sustainability of the solar appliance sector, including:

- **Knowledge gaps**: Consumers are not aware of where to take their appliances when they become faulty after the warranty period ends.
- **Access to repair services**: Spare parts for solar appliances are not easily and locally available.
- **Missed job opportunities**: Informal repairers are not trained to repair most solar appliances and thus rely on previous experience, as well as trial and error.

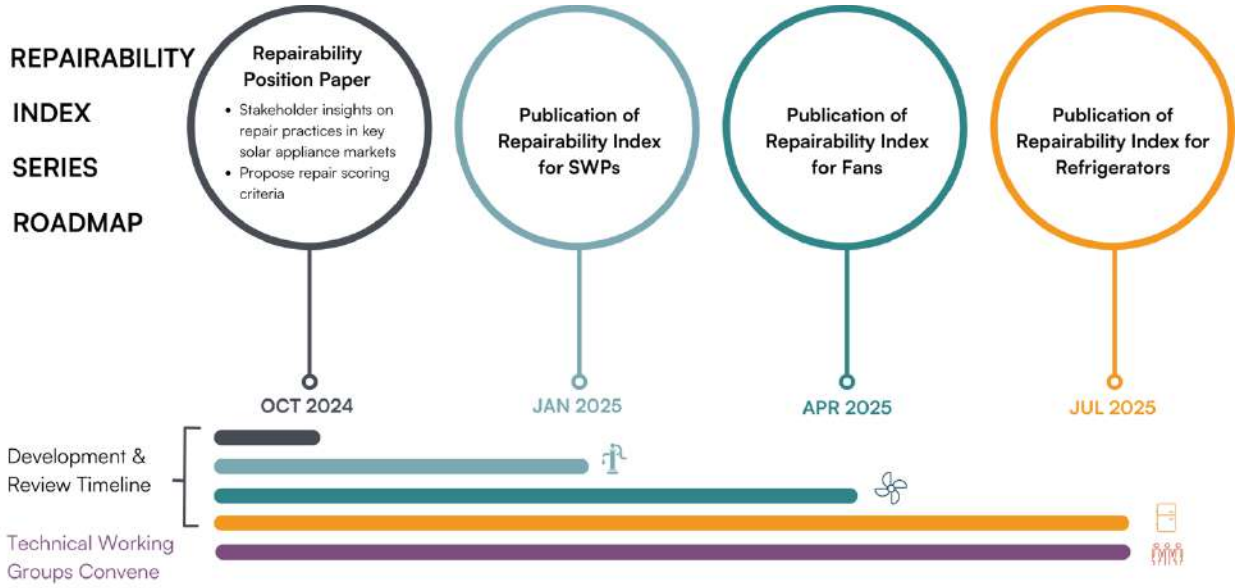
This paper incorporates these insights into the development of a repairability index for solar appliances. The solar appliance repairability index aims to serve as the foundational building block in guiding decisions related to product design interventions, business models, and workforce and skills requirements, with the ultimate goal of helping to extend the lifespan of solar appliances.

Four key parameters that are crucial in the design of the index include:

1. **Availability of parts and components**
2. **Complexity of the skills required for repair**
3. **Ease of disassembly**
4. **Availability and access to the documentation detailing the repair process**

This paper is the first in a series on repairability, as illustrated in Figure 1 below. This introductory paper outlines findings of current repair practices and proposes the key criteria for assessing repairability. The Technical Working Groups (TWG) will convene after the upcoming Global Off-Grid Solar Forum in October 2024, where a large contingent of manufacturers, distributors, and regulators are expected to attend. We will present the findings of this report in a dedicated repair session and recruit interested parties to the TWG. The information in this paper will provide the background context and key factors that the TWG will consider in developing a repairability index for specific appliances. By the end of the series, in collaboration with stakeholders, we will have developed repair indices for solar water pumps, fans, and refrigerators.

Figure 1: Report roadmap: the repairability index series

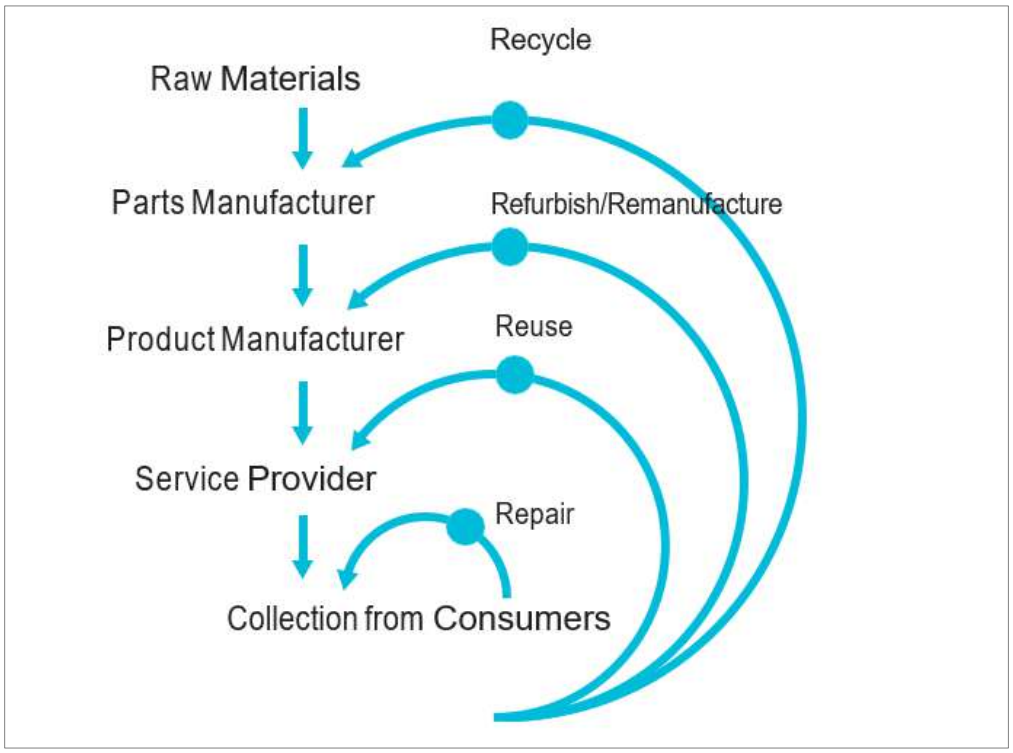


Current Repairability Insights

Improving the repairability of solar appliances offers the off-grid solar appliances sector an opportunity to demonstrate leadership on electronic waste (e-waste) and the circular economy, while enhancing value for consumers and companies.

Growing off-grid solar markets are enabling energy access for millions of vulnerable communities.[1] However, the proliferation of solar home systems and solar appliances poses a potential threat to the environment and customer satisfaction if not properly managed during failure or end of life.[2] Figure 2 showcases the circularity cycle for most appliances.

Figure 2: Typical cycles of circularity for appliances[3]



Source: Pathways to Repair in the Global Off-Grid Solar Sector, Efficiency for Access Coalition and the University of Edinburgh (October 2020)

High costs of recycling remain one of the most significant barriers to improving e-waste management practices. The lack of e-waste infrastructure and service providers in Africa is another barrier, including the absence of recycling facilities that meet minimum standards and

[1] GOGLA_Sales-and-Impact-ReportH2-2023_FINAL.pdf
[2] Efficiency for Access, Global LEAP Solar E-Waste Challenge: Lessons on Take-Back, Collection, Repair & Recycling of Off-Grid Solar Products, March 2021. (https://efficiencyforaccess.org/wp-content/uploads/Clasp_EforA-SolarEWaste_5-May.pdf), accessed Aug 23, 2024
[3] Pathways-to-Repair-in-the-Global-Off-Grid-Solar-Sector_final.pdf (page 19)

the difficulty of finding the spare parts necessary for repair.[4] Additionally, the growth rate of countries implementing e-waste policy, legislation, or regulation is decelerating.[5]

As a process, repair involves the restoration or correction of malfunctioning, damaged, or broken appliances, and aims to bring them back to their original or functional state. Repair focuses on addressing and resolving issues once an appliance has already experienced failure.[6] **Repairing an appliance is a way to preserve value by slowing down the appliances' economic devaluation**.

In the absence of repairable appliances, companies risk losing customers due to low satisfaction. Repair is a promising customer retention / service strategy. A longitudinal study from Efficiency for Access[7] revealed that 49% of respondents reported "appliance breakdown" as the reason why they stopped using their appliance. This survey also showed that households and companies in Kenya face high costs of solar appliances, with over 80% of purchases made on credit, demonstrating the significance and value of these appliances to the owners.

Consumers who cannot afford to replace an appliance with a new one might be able to spend less by repairing it. Repairing the appliance will also help consumers extend the return on their initial investment, all while retaining access to the appliance's service. For companies, such as those selling appliances on Pay-As-You-Go (PAYGo), enhanced repair ensures a continued revenue stream; an appliance that is out of action represents lost income and customer dissatisfaction.

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[4] Efficiency for Access, Global LEAP Solar E-Waste Challenge: Lessons on Take-Back, Collection, Repair & Recycling of Off-Grid Solar Products, March 2021. (https://efficiencyforaccess.org/wp-content/uploads/Clasp_EforA-SolarEWaste_5-May.pdf), accessed Aug 23, 2024

[5] Global E-waste Monitor 2024, accessed Aug 23, 2024 (https://www.itu.int/en/ITU-D/Environment/Pages/Publications/The-Global-E-waste-Monitor-2024.aspx)

[6] These definitions have been adopted for this paper.

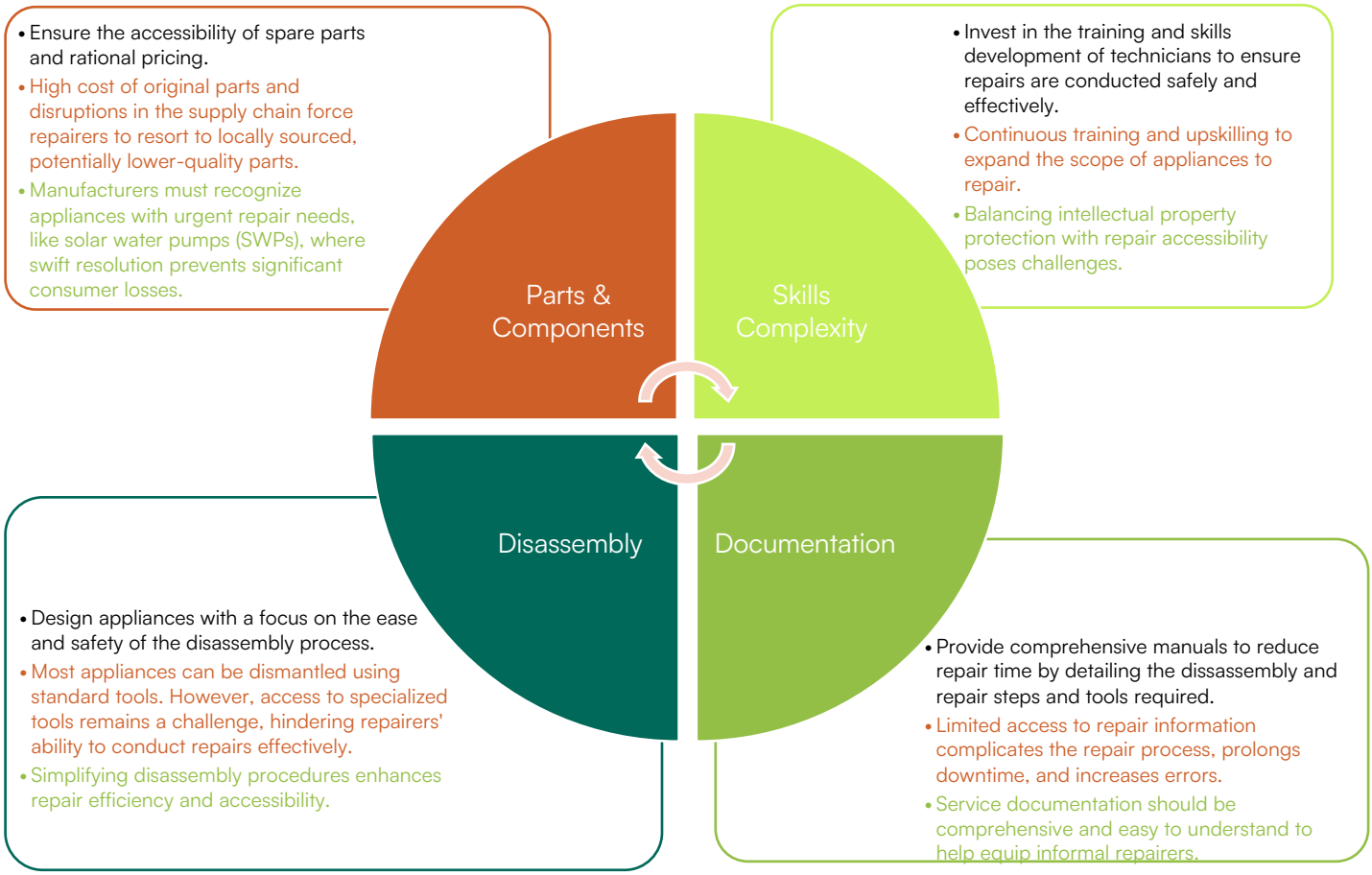
[7] "Appliance-Impacts-Over-Time," Efficiency for Access, accessed June 20, 2023, https://storage.googleapis.com/e4a-website-assets/Appliance-Impacts-Over-Time.pdf.

Repairability Index at a Glance:

KEY FINDINGS

Stakeholder conversations and interviews conducted during this research uncovered key insights and recommendations for solar appliance repair, as summarised in Figure 3.

Figure 3: Key insights and recommendations from stakeholder interviews



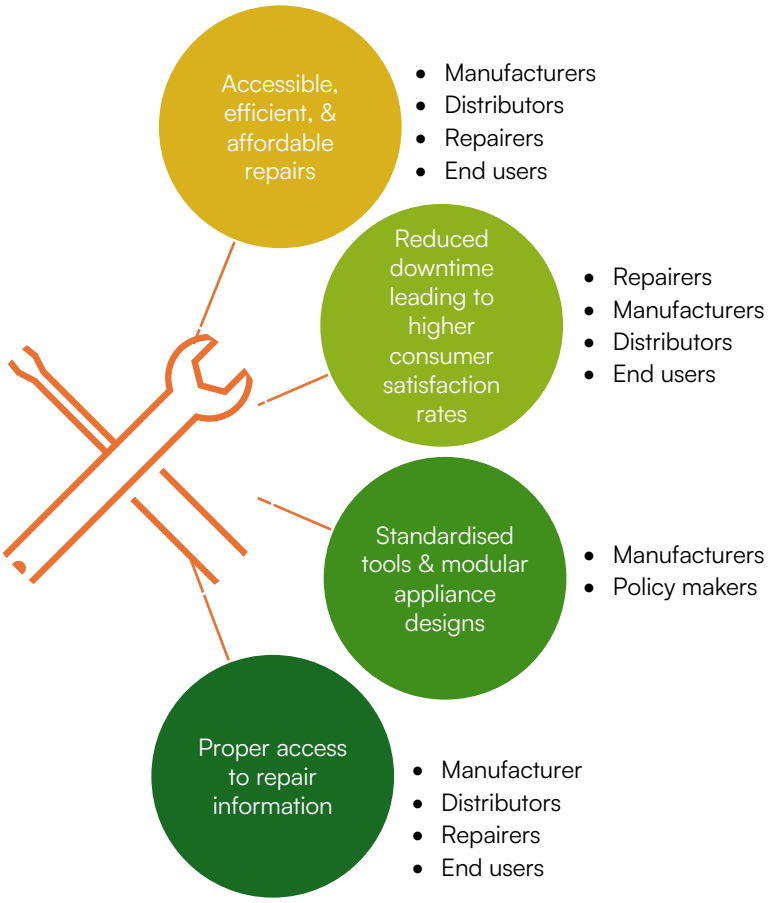
Key:

- Manufacturer / Distributor Insights
- Repairer Insights
- Insights from researchers/policy makers

IMPACTS OF IMPROVED REPAIRABILITY

Figure 4 outlines the potential impacts of improved repairability and the roles of different stakeholders in realising these impacts.

Figure 4: Impacts of improved repairability and stakeholder roles.



Proposed Repairability Index Criteria

Based on stakeholder feedback, we propose a set of criteria designed to assess the impact of repair on two distinct target groups. These groups should be able to address different levels of repair issues, depending on complexity and the expertise needed to solve it:

- **Informal repairer:** This category consists of individuals with electrotechnical training, but who are not contractually affiliated with the manufacturer or authorised service partners. The criteria consider the requirements and challenges these professionals face when carrying out repairs or upgrades. They should have access to the tools, spare parts, knowledge, and safety equipment to do the repairs for at least the listed priority parts.

- **Authorised service partner:** This category considers professionals with relevant electrotechnical training who are contractually linked to the appliance manufacturer or distributor. They represent the highest level of expertise and should be able to handle out-warranty and warranty level issues, complex repairs that may compromise the integrity of an appliance, overhauls, and refurbishment, etc.

With these two target groups, the assessment ensures a suitable index for product repairability and covers the wide range of stakeholders involved across repair processes. The scoring parameters proposed are:

1. **Parts and components**
2. **Skills complexity**
3. **Disassembly**
4. **Documentation**

1. Parts and Components

Spare parts can be defined as a removable component of an appliance that can replace a part with the same or similar function. Germany's Blue Angel Label[8] defines spare parts as appliance components that may break down within the scope of ordinary use, excluding parts that normally exceed the life of the appliance.[9] The Benelux proposal on repairability criteria for energy-related products highlights that although all components of an appliance can fail, a cut-off rule is important to identify priority parts[10] and failure modes. The French Repairability Index[11] highlights spare parts as a crucial component of the repair and servicing ecosystem of appliances. The index considers the availability and price of spare parts as the two main criteria. The Benelux proposal on the other hand goes further by considering information related to spare parts as one of the criteria for evaluating repairability. This paper follows the Blue Angel Label

[8] https://www.blauer-engel.de/en
[9] Ellen Bracquené, Brusselaers Jan, and Dams Yoko, "FINAL_Report_Benelux.Pdf."
[10] Parts and components of a product that are exposed to particular wear and tear and might have a higher failure rate.
[11] Marcus Bergmann and Ronan Bergmann, "Rapport-Indice-de-Reparabilite.Pdf," Halte à l'Obsolescence Programmée, accessed May 11, 2023, https://www.halteobsolescence.org/wp-content/uploads/2022/02/Rapport-indice-de-reparabilite.pdf.

definition, which includes parts that typically break down within the ordinary use of an appliance, primarily due to wear and tear.

This repairability index report examines the different aspects of priority parts that affect appliance repairability.

Photo caption: Bonnie, a repair technician, at his shop at Nyayo Market in Nairobi, Kenya

Availability of Priority Parts

Priority parts for solar appliances are mainly sourced from China, India, Mexico, Germany, and the United States,[12] with a few original equipment manufacturers spread out across major markets. For expanding solar appliance markets, such as those in Africa and South Asia, **appliances and their spare parts are shipped from international markets. This means that shipping and customs clearance affect the accessibility of these products in their intended**

[12] Volza. 2023. "Solar Submersible Pump Export Data of the World." https://www.volza.com/p/solar-submersible-pump/export/

markets.[13] Minimum purchase quantity thresholds set by some overseas manufacturers further impede availability for small and medium-sized enterprises.

A solar water pump (SWP), for instance, has relatively more priority parts compared to a fan. SWP manufacturers thus have a greater commitment to making these priority parts available to end users. The French Repairability Index evaluates availability of spare parts based on the manufacturer's commitment to providing priority parts for a set period, as well as the expected delivery time for each product. **Additional criteria should be included to account for the complex and nuanced nature of off-grid markets.**

A more elaborate and inclusive repairability index should also consider:

- Point of availability,
- Availability to different actors,
- And the duration that spare parts are available.

For instance, categorising priority part availability based on who can access these parts (the public, informal repairers, authorised repairers, or manufacturer only) acknowledges that access influences the overall repairability process and end user satisfaction.

Point and Duration of Availability

Depending on the manufacturer, some priority parts may be made available during purchase, while others are only available when an appliance breaks down, or upon request from the seller. Futurepump, for instance, includes a set of spare parts and tools in the SF2 product package during purchase.[14] For most appliances, however, spare parts are sold separately and only when a part breaks down or when taken in for repair. This limits their accessibility and continuous use of the appliance in question, especially in rural areas, and greatly influences their repairability.

[13] There are no sources in the current document.

[14] ReAg Tools. 2023. Futurepump SF2 Datasheet. 28 June. Accessed September 19, 2023. https://reagtools.co.uk/blogs/instructions/futurepump-sf2-datasheet.

Photo caption: Some of the spare parts and tools provided at purchase for the Futurepump SF2 pump.

Although the specific timeline for how long a manufacturer is obliged to make spare parts available differs by appliance and country, **best practice requires that priority parts be made available for at least the lifetime of an appliance and even after it is phased out from production**. The delivery time for priority parts is often calculated in working days between the day of order confirmation, to the arrival/delivery of the part. Service level (SL), which is a common metric for evaluating performance of aftersales services, is used to calculate and score the service level related to priority parts fulfilment requests. While the European Commission standard requires that spare parts be delivered within 15 days, the fulfilment time varies by appliance, including the maturity of distribution channels.

In nascent markets where distribution channels are not well established, the delivery time may be much longer, especially as the appliances are targeted to rural off-grid populations that are impacted by general infrastructure deficits. Thus, manufacturers cannot always guarantee delivery periods, especially from third party original equipment manufacturers (OEMs) or distributors. The practicality of the delivery time influences the decision of a consumer to repair the appliance or not.[15] For solar appliances, this criterion requires factoring in additional aspects, such as appliance market maturity, where a mature appliance with an established supply chain scores lower if the stated delivery time was the same as a rather nascent appliance.

[15] Ritthoff, Michael, Anne Müller, Lucie Hopfensack, and Environment and Energy, Wuppertal Institute for Climate. 2023. ***Methods and Standards for Assessing the Repairability of Electrical and Electronic Appliances: Strengthening Material Efficiency Under the Ecodesign Directive.*** German Environment Agency.

Cost of Priority Parts

The cost of a priority part greatly influences the affordability and eventual repairability of an appliance. The French Repairability Index looks at affordability of spare parts as a standalone criterion, while the Benelux proposal includes cost under the overall criteria for spare parts. Both, however, use a similar approach, in which affordability is calculated as a percentage of the total cost of the product. From the catalogues provided by the manufacturers, the metric is calculated as an average of the most expensive priority part and the average price of the remaining priority parts, which is then divided as a percentage from the pre-tax price of the complete product:

Affordability metric = [(pre-tax price of the most expensive priority part + average pre-tax price of the remaining priority parts) ÷ 2] ÷ pre-tax price of the complete appliance.

In cases where the prices of these parts vary, the average price within the period is used to calculate the score.[16] This method of scoring affordability is largely standard with various guidelines, including the Benelux proposal and the French Repairability Index using a similar approach, and could be adopted for the off-grid solar appliance sector.

2. Skills Complexity

In the rapidly evolving solar appliance industry, complex repair issues should be handled by a network of qualified experts. These experts should have access to high-quality replacement parts, repair information, repair tools, and easily repairable solar appliances.[17] A survey of the solar e-waste ecosystem in Kakamega County, Kenya revealed that most consumers seek to repair out-of-warranty solar appliances with local technicians that are often informal repairers. During COVID-19 restrictions, demand for home-based repair services increased, highlighting the need to ensure technicians possess the necessary skills to service these appliances.[18]

[16] Ministère de la Transition écologique. 2022. "Instructions Manual for the Display and the Calculation of the Repairability Index of Electrical and Electronic Equipment."
[17] SolarAid - Tackling Solar e-waste: Solar-e-waste.pdf (solar-aid.org)
[18] Clasp_EforA-SolarEWaste_5-May.pdf (efficiencyforaccess.org)

Photo caption: Repair technician Steven disassembling a microwave in Kenya.

In the off-grid solar industry, technicians are the key personnel required to facilitate after-sales service and support, which includes appliance repair. **However, there is a significant skills mismatch in the sector, such as limited practical experience, lack of knowledge of current technologies in use, lack of dedicated training courses, and inadequate soft skills, especially for solar-powered irrigation.** This mismatch is particularly pronounced in rural areas due to urban skill concentration.

To improve the maintenance and repair of solar appliances, local experts should be trained via specifically designed certification programmes.[19] There are a growing number of off-grid solar technician certification courses offered by local universities and technical and vocational education and training (TVET) centres in Kenya. Data gathered from stakeholder interviews conducted in March 2023 showed that a diploma or degree in electrical/mechanical fields is required for the courses, making them appropriate only for professionals and individuals with electrical experience. However, some courses are available for post-high school graduates. TVETs/Educational institutions, government bodies, off-grid solar companies, and development programmes need to collaborate to strengthen the off-grid solar curriculum to ensure students have the necessary skills to service this market.

The Energy and Petroleum Regulatory Authority (EPRA) licenses technicians as practitioners for solar solutions in Kenya. The minimum requirement needed to install, maintain, and repair solar appliances is a solar PV training certificate from any accredited institution. Overall, while training for this certification is available, it is still quite expensive and primarily available in urban areas, making it inaccessible to people in rural areas where most solar appliances are typically deployed. **This underscores the need to develop and implement training courses specifically intended for solar appliance repair technicians. Manufacturers and distributors alike should**

[19] Appliance-Impacts-Over-Time.pdf (efficiencyforaccess.org)

leverage local academic and vocational training institutions, as well as technician networks, to ensure that consumers have access to skilled and competent repair technicians across the markets they serve.

A recently published jobs report highlights the significance of building skills suitable for the solar appliance sector by estimating that the solar irrigation sector in India and Kenya alone has the potential to create more than 115,000 jobs by 2030.[20]

Photo caption: A second-hand solar appliances and repair shop in Nairobi (Ngara Market), Kenya

3. Disassembly

The Benelux proposal on the practical application of the circular economy describes disassembly as a **non-destructive process that involves taking apart an assembled appliance into constituent materials and/or components.**[21] It emphasises the reversible nature of disassembly, enabling subsequent reassembly and operational functionality. According to the Encyclopedia of Production Engineering, disassembly involves the process of separating an assembled appliance into its components and/or subassemblies using non-destructive or semi-destructive operations that primarily affect the connectors and fasteners.[22]

[20] Efficiency for Access, Green Jobs for Rural Youth: Unlocking Renewable Energy's Potential in Agriculture, August 2024, https://efficiencyforaccess.org/wp-content/uploads/Green-Jobs-for-rural-youth.pdf

[21] Ellen Bracquené, Brusselaers Jan, and Dams Yoko, "FINAL_Report_Benelux.Pdf," June 2018, https://www.benelux.int/files/7915/2896/0920/FINAL_Report_Benelux.pdf

[22] Paul Vanegas, Jef Peeters, and Joost Duflou, "Disassembly," in ***CIRP Encyclopedia of Production Engineering***, ed. Luc Laperrière and Gunther Reinhart (Berlin, Heidelberg: Springer, 2014), 395—99, https://doi.org/10.1007/978-3-642-20617-7_6636.

Photo caption: Steven, a repair technician, at work in Nairobi, Kenya

Conversely, **if the product separation process is irreversible, it is referred to as dismantling or dismounting**. The objective of disassembly is to allow for the systematic and efficient removal of components or subassemblies, facilitating repair, replacement, or recycling.

Enhancing the ease of disassembly offers economic incentives to recycle end-of-life appliances and components. An increased ease of disassembly not only reduces the time required for separating materials into appropriate processing streams, but also enhances the perceived value of the "waste" as more materials can be effectively recovered.[23]

Multiple factors come into play when considering the ease of disassembly as a criterion for repairability. These include:

- **Identification and accessibility of priority parts within the product (number, type, and positioning),**
- **The need for common or specialised tools,**
- **And the precision, force, time, and steps involved.** [24]

[23] Pathways-to-Repair-in-the-Global-Off-Grid-Solar-Sector_final.pdf

[24] Mauro Cordella, Felice Alfieri, and FORNER Javier Vicente Sanfelix, "Analysis and Development of a Scoring System for Repair and Upgrade of Products," JRC Publications Repository, March 26, 2019, https://doi.org/10.2760/725068.

Required Tools

The choice and availability of tools greatly impacts the disassembly process. Proper tools not only aid in safely and effectively separating materials and components, but also contribute to reducing the complexity of disassembly and therefore time and effort associated with the process. The tools needed for repair are determined by the appliance design, making them an objective characteristic. The simplest disassembly should be achieved through procedures that require no tools.

Photo caption: A repairers' work bench with typical repair tools on display

Nevertheless, when disassembly without tools is not feasible, **prioritising designs that accommodate standardised or generic tools is preferable, as these are more widely accessible**. Manufacturers play a significant role in defining the complexity of the disassembly process. The European Standard (EN) 45554:2020 offers a globally recognised and standardised method for defining the characteristics of an appliance that is considered "repairable."[25] This standard provides a list of basic tools that are most commonly used for repair and have been used to shape the ease of the disassembly criteria. It is important to acknowledge that not all repairers, particularly informal repairers, have every tool listed or possess the

[25] "EN 45554:2020 - General Methods for the Assessment of the Ability to Repair, Reuse and Upgrade Energy-Related Products," iTeh Standards, accessed June 13, 2023, https://standards.iteh.ai/catalog/standards/clc/ed9b48c0-a4a9-421a-a14f-4ff341199918/en-45554-2020.

necessary skills to use them. For appliances where self-repair or informal repair is more prevalent, common screwdrivers or bit sets should typically suffice.

Basic tools commonly used for appliance repair:

- Screwdrivers for slotted heads, cross recess, or hexalobular[26] recess heads
- Hammer, stell head
- Hexagon socket key
- Combination wrench
- Combination pliers
- Half round nose pliers
- Diagonal cutters
- Multi-grip pliers (multiple slip joint pliers)
- Locking pliers
- Combination pliers for wire stripping and terminal crimping
- Prying lever
- Tweezers
- Utility knife (cutter) with snap-off blades
- Multi-meter
- Voltage tester
- Soldering iron
- Hot glue gun
- Magnifying glass

Disassembly Depth

The ease of disassembly is significantly influenced by the number of steps involved in the disassembly process, commonly referred to as disassembly depth. Disassembly depth is the sequence of steps necessary to remove components, which may involve accessing fasteners or other mechanisms.[27]

Each step comprises an operation that concludes with the removal of a part or change of tool. Analysing disassembly depth is essential to evaluate the effort required to access and replace priority parts or components when repairing an appliance. Providing information about the specific steps required to disassemble certain parts, along with design choices that minimise the number of disassembly steps, can facilitate repair and upgrades.

The numerical nature of the process allows for easy comparison of working steps among different appliances. However, this approach falls short when evaluating the repairability of a single appliance in isolation. The true significance of the number of steps emerges when comparing it with other similar appliances. Additionally, although a ranking of appliances can be established based on the number of steps, it is not clear how to incorporate the differences

[26] The ISO name for a type of screw drive that is also known as Torx, 6-Lobe, or star drive.
[27] Definition adopted for the appliances in scope for this paper.

between appliances into the evaluation. For instance, two appliances may have a similar number of steps required for dismantling a motor, while another appliance might necessitate nearly double the number of steps.[28] If we ranked these appliances (1st, 2nd, and 3rd), simply penalising the second ranked appliance in the ranking would fail to properly reflect the much longer process for the third ranked appliance.

To address these challenges, one potential solution is to employ reference values, which enable the assessment of any deviation in the number of steps from an established reference value. The utilisation of reference values is also a key component of the evaluation system outlined in the EN 45554 standard.[29] These reference values could be generated from an anticipated maximum number of steps. The mean value for the number of steps required to remove each priority part over all appliances in an appliance group can also serve as a reference value. It is important to note that scoring would likely differ for each appliance group, since the number of disassembly steps required would depend on the appliance type.

A work step, in the context of disassembling solar appliances, is an individual operation within the disassembly process that leads to the removal of a priority part or component and/or a change of tool. Drawing from the French Repairability Index, certain actions are excluded from being counted as a step in the disassembly process. These include activities like picking up a tool, setting a tool down, placing a fastener aside, or partially disconnecting a subset or pipe. For safety reasons, the action of "securing the internal active parts of the appliance" is also considered a step, regardless of the number of manipulations required. This applies even if it does not involve changing tools or removing a part or component. Examples of such actions might include tasks like unplugging the equipment from a power source. It's important to bear in mind that, in this context:

- The hand is not considered as a tool.
- A fastener is not regarded as a part.[30]

Disassembly depth also plays a crucial role in the creation of disassembly maps, which serve as visual guides illustrating the step-by-step process of dismantling an appliance. By capturing the sequential order of disassembly steps, these maps offer a valuable resource for effective and organised disassembly, enabling smoother maintenance and repair procedures.[31] Manufacturers are encouraged to make the disassembly sequence available for each priority part to target groups of repairers, in this case, constituted mostly by informal repairers.

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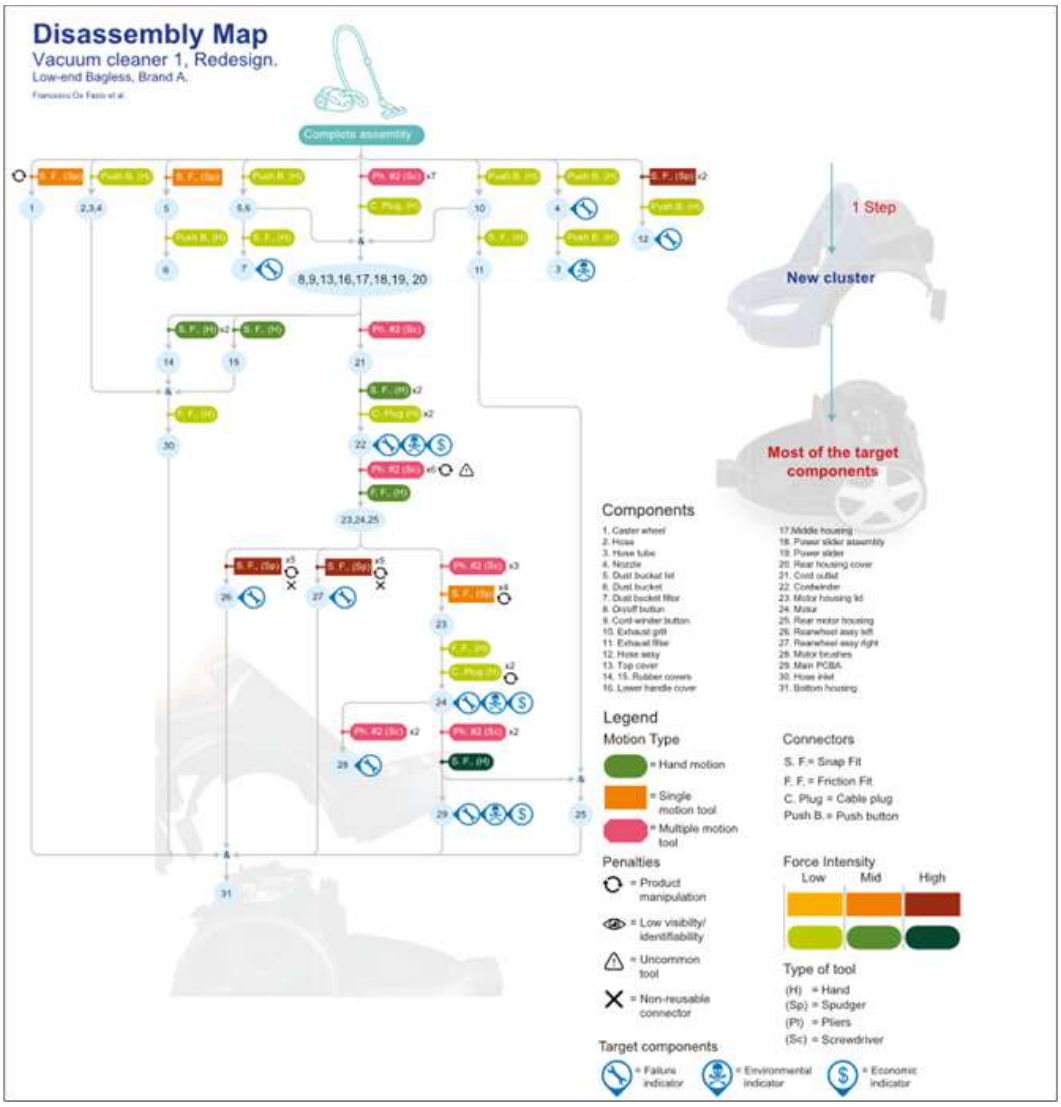
[28] Martin Stallmann, ***Methods and Standards for Assessing the Repairability of Electrical and Electronic Appliances*** (Umweltbundesamt, 2023), https://www.umweltbundesamt.de/en/publikationen/methods-standards-for-assessing-the-repairability.

[29] BS EN 45554:2020 General methods for the assessment of the ability to repair, reuse and upgrade energy-related products (en-standard.eu)

[30] Ministry of Ecological Transition, "Instructions Manual for the Display and the Calculation of the Repairability Index of Electrical and Electronic Equipments" (Ministry of Ecological Transition, June 28, 2022), https://www.ecologie.gouv.fr/sites/default/files/220523_instructions%20manual%20-%20repairability%20index%20-%20final%20V3.0.pdf.

[31] Francesco De Fazio et al., "The Disassembly Map: A New Method to Enhance Design for Product Repairability," ***Journal of Cleaner Production*** 320 (October 20, 2021): 128552, https://doi.org/10.1016/j.jclepro.2021.128552.

Figure 5: Disassembly map example for a vacuum cleaner[32]



Source: The Disassembly Map: A new method to enhance design for product repairability, Journal of Cleaner Production (October 2021)

4. Documentation

Repairing an appliance is an established way to preserve its value by increasing its in-use lifetime, which slows down the appliance's economic devaluation. One of the key barriers to appliance repair is the lack of information and guidance provided by manufacturers or sellers on repair requirements and processes. This report proposes criteria that assess the quality of technical repair documentation provided with an appliance at the point of purchase. It is worth noting that warranties are critical in the case of serviced repair. However, beyond the warranty

[32] The Disassembly Map: A new method to enhance design for product repairability (sciencedirectassets.com)

period, which is the focus of this paper, most repair is intended to extend the use of the appliance by correcting specific faults, bringing the appliance back to a safe and good working condition.[33]

Consumers need to know how to use appliances and be protected in the event of appliance failure. A possible way to achieve this, beyond provision of repair information at the point of purchase, is through the development of **a centralised repository for repair documentation**. This would ensure access to the necessary information for consumers and repair technicians alike. Such a repository should be in the form of an online database / tool where the faults found at the point of diagnosis are matched with the recommended solutions, alongside required tools, contacts, and addresses for repair technicians and/or service centres. This can be enhanced with translations into the major languages spoken in the intended markets.

Repair manuals should be easily accessible, readable, understandable (self-explanatory), free of charge, and as simple as possible. They should be enhanced using visual aids and other relevant graphics.

Access to these manuals should be facilitated using Quick Response (QR) codes, which can be decoded to retrieve a link to access online information. To maximise accessibility, the required technical documentation could also be made available as physical copies included in the product packaging and / or virtual documents available on a navigable website or database.

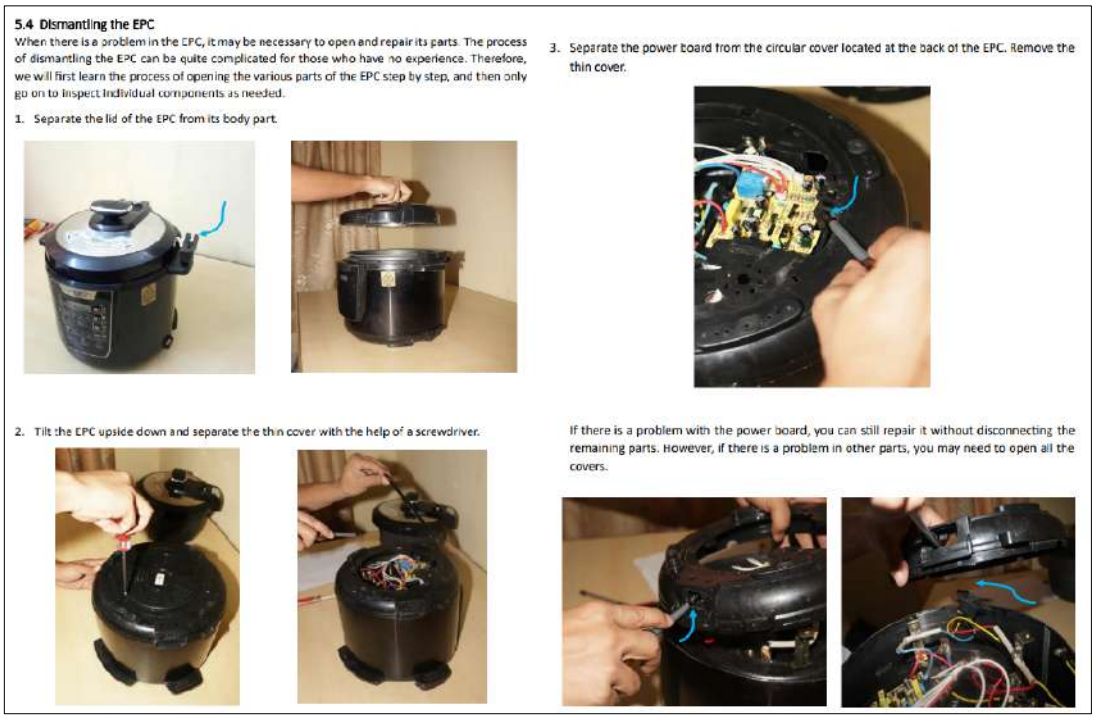


Photo caption: Snapshot from a Repair Manual for Electric Pressure Cookers (MECS EPC Repair Manual) [34]

[33] (PDF) Developing a reparability indicator for electronic products (researchgate.net)
[34] Repair-Manual-Electric-Pressure-Cooker-1.pdf (mecs.org.uk)

The Benelux proposal[35] offers some guidance on what should to be included in a typical repair manual. This has been adapted slightly to suit the appliances included in this research. Our recommendation is that repair manuals should contain the following information:

Table 1: Recommended information for repair manuals

	MANUFACTURER'S SERVICE CENTRES (AFTER SALES SERVICES)	DISASSEMBLY OF AN APPLIANCE	INDEX FOR SPARE PARTS
Instructions	Address, phone number, and business hours for customer enquiries should be provided to the consumer directly by the manufacturers or through retailers.	○ Kind of repair tools needed and their availability ○ Information about type and number and location of connections ○ Description of actions that must be carried out to repair the product (basic fault diagnostic advice and troubleshooting tree)	Include information on where to get spare parts and their cost.
Services offered	○ A substitute for the original appliance during the repair time ○ The possibility to get repair swiftly ○ Assistance in fault diagnostics ○ Appliance maintenance instructions		

- **Manufacturer service centres (after sales services):** address, phone, and business hours should be provided to the consumer directly by the manufacturers or through retailers. We recommend that this service should offer:
  - A substitute for the original appliance during the repair time
  - The possibility for repair to be undertaken swiftly
  - Assistance in fault diagnosis

[35] https://www.benelux.int/files/7915/2896/0920/FINAL_Report_Benelux.pdf

    - Support for repair operations
    - Appliance maintenance instructions

- **Instructions for disassembly of an appliance including:**
    - Type of repair tools needed and their availability
    - Information about type, number, and location of connections
    - Description of actions that must be carried out to repair the product (basic fault diagnostic advice and troubleshooting tree)

- **Index for spare parts**, which includes information on where to get spare parts and their cost.

Aside from the content, the structure of the repair manual and the ease of retrieving the required information for performing repair operations is of high importance.

The documentation should be clear on who the target audience is. As most appliances covered in this scope have multiple components, self-repair by end users is not encouraged and therefore the repair manuals should be targeted to people with some repair expertise. Appliance repairs are typically done by an informal repairer or an authorised repairer. The distinction between these is provided below:

- **Authorised repairer/service partner:** The authorised repairer is often an authorised service centre. These are professional repairers for whom one or more contracts precisely defines the relationship between the repairer and the appliance producer(s).
- **Informal repairers:** These are independent repairers in the sense of "professional craftsmen", usually more informal but still skilled technicians. They are repairers who do not have any contractual agreement or affiliation with appliance manufacturers or distributors.

For disassembly instructions, the provision of a disassembly map is recommended, as it serves as a visual guide illustrating the step-by-step process of dismantling an appliance. By capturing the sequential order of disassembly steps, these maps offer a valuable resource for effective and technically correct disassembly, enabling smoother repair and maintenance procedures.[36]

It is advisable to add extra textual and pictorial explanation or examples to the different rating levels where needed. Guidance on which components should only be handled by authorised repairers and which can be handled by informal repairer is recommended to limit potential breaches of warranty cases. Manufacturers are encouraged to make the disassembly sequence available for each priority part.

[36] The Disassembly Map: A new method to enhance design for product repairability - ScienceDirect

While this report proposes a general framework for repair assessment, the outlined methodology is not complete. Specifically additional steps required include:

- Setting the weighting factors for each parameter,
- Defining the list of priority parts for each appliance category,
- Comparing relative price of spare parts,
- Determining the mean value of disassembly steps and similar benchmarks for disassembly,
- Defining the procedure to assess required skills,
- Defining the lifespan of each appliance, and
- Defining limiting factors to avoid illogical scenarios.

Each proposed parameter would then be assessed and scored based on the level of repair it allows, contributing to the calculation for an overall repairability score for each individual appliance. This would be presented in the form of a RAG rating[37] as outlined below:

Figure 6: RAG rating for appliance repairability

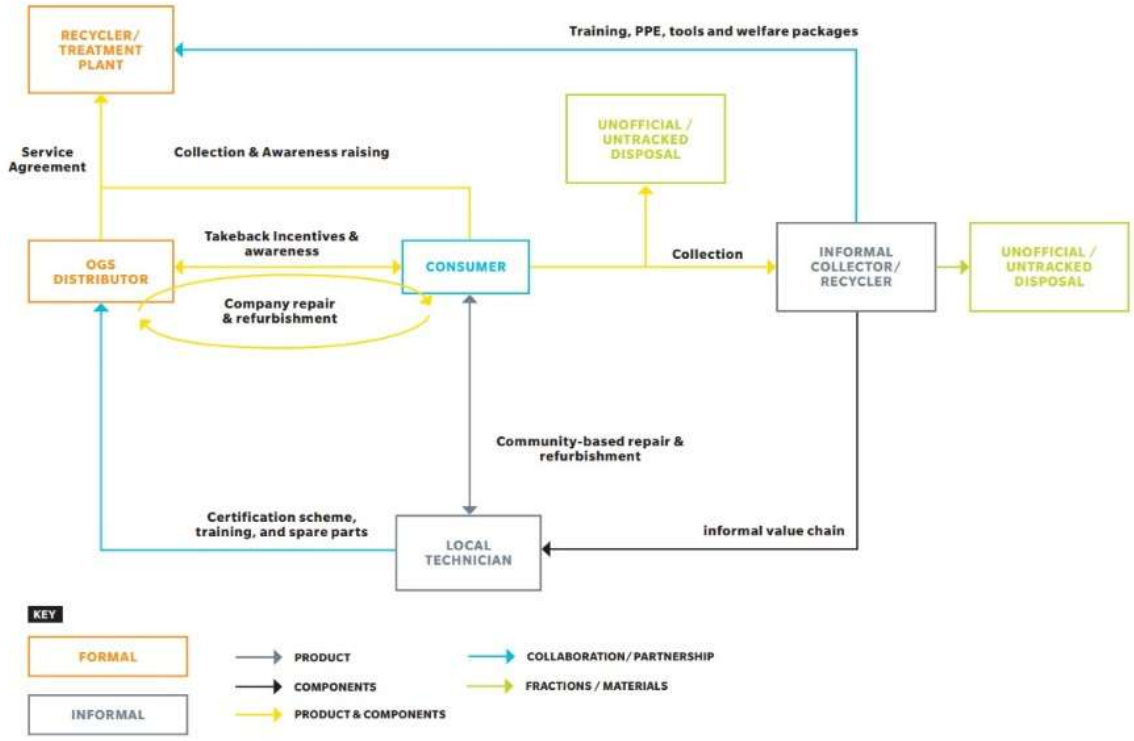
SCORE	0	1	3	5
	Repair is not feasible	Repair is feasible but very complex. Only possible for manufacturer and authorized service partners, very low consideration to enable informal repair.	Repair is feasible and modest. It can be carried out by informal repairers, adequate access to spare parts, tools, and information to facilitate repair.	Repair is feasible and straightforward. It can be done by a layperson, full, and open access to all spare parts, tools, and information needed for repair.

[37] A RAG (Red, Amber, Green) rating is a practical tool for assessing the status of a project or activity.

Stakeholder Insights

The Global LEAP E-waste Challenge[38] revealed that **appliance manufacturers have a pivotal role to play in advancing sustainable product lifecycle practices within the repair ecosystem**[39] (***Figure 7***).

Figure 7: The off-grid solar e-waste ecosystem, informed by Global LEAP projects.[40]



Source: Innovations and Lessons in Solar E-Waste Management, Efficiency for Access (March 2021)

> ***"An ideal repair index should reward intelligent appliance designs — appropriate design for the specific use cases — that prioritise reliability and safety without compromising on product quality." - Appliance manufacturer.***

Manufacturers and distributors alike should ideally strive to better educate their customers to use appliances to extend their life, thus reducing potential for breakdown and subsequent repair. However, the cost of consumer education can be prohibitively high for many appliance companies that are small and managing the cost of last mile distribution.

[38] Solar E-Waste Challenge - Efficiency for Access
[39] This insight was corroborated by stakeholder feedback collected in 2023 during this study.
[40] Clasp_EforA-SolarEWaste_5-May.pdf (efficiencyforaccess.org)

> ***"Manufacturers should consider that certain products have a more urgent need for quick, accurate and robust repair that others. For instance, if I'm a farmer with a water pump and my water pump fails yet the rains are not falling, I could suffer very significant losses if I don't get the pump repaired fast enough." - Sector Association***

Sector experts and academia advocate for a consumer focus on using priority parts and components. They encourage distributors to ensure that consumers receive fully functional systems. They also propose simplifying disassembly procedures to enhance repair efficiency by last mile distributors. Manufacturers were tasked to identify appliances with urgent repair needs, like solar water pumps (SWPs), where swift resolution of faults/defects prevents significant user losses and payment defaults where purchase was made on PAYGo. **Additionally, assessment criteria should consider software accessibility, reflecting its importance in modern appliances.**

> ***"A lot of solar appliance companies only allow repairs by their certified technicians, and these are often inaccessible to a lot of their customers unless you happen to live near a big town. This thus leaves the customers with the choice between going to a local 'fundi' (technician) and violate the warranty but it's affordable and accessible, versus trying to access these faraway warranty services." - Spare parts distributor.***

Manufacturers recognise that focusing on the ease and safety of the disassembly process, ensuring the availability of priority parts and repair information, and investing in skills for quality repairs can significantly contribute to improving appliance repairability, consumer satisfaction, and environmental sustainability. Though they acknowledge the significance of their role, many manufacturers shared concerns around this responsibility that they would like to see addressed, including:

- Protecting their intellectual property to prevent counterfeits,
- Bearing the cost of holding large volumes of spare parts stock,
- And absorbing the cost of training technicians who are informal and therefore not full-time staff.

> ***"To improve repairability, manufacturers should standardise parts and connections for appliances, provide instructions on how to disassemble and repair, and indicate who should conduct repair - specialised technician or any technician. Most of the time, information on how to repair and support contacts is not provided, which hinders repair."- Repairer***

All stakeholders highlighted the multifaceted challenges and opportunities that repair technicians face in their endeavour to maintain and extend appliance lifespan. As part of the interviews, we asked the respondents to rank constraints from highest to lowest based on what they thought would have the greatest impact on improving the repair process.

Availability of spare parts was ranked first most frequently, followed by the complexity of skills required at second. The ease of disassembly and availability of repair documentation were ranked third and fourth respectively. End of life considerations were ranked least important, as these typically do not have a direct impact on appliance repair. ***Table 1*** shows how different stakeholder groups ranked each of these parameters by order of importance for the repair process.

Table 2: Ranking of proposed parameters by order of importance to different stakeholder groups.

	Manufacturers / Distributors (n=6)	Test Labs (n=2)	Sector Associations (n=1)	Academia (n=2)	Repairers (n=5)
Spare parts & components	1	2	1	4	2
Disassembly	3	4	2	3	4
Skills complexity	2	3	3	2	1
Documentation	4	1	4	1	3
End of life	5	5	5	5	5

The challenges highlighted are detailed below:

i. **Navigating spare parts availability:** Securing spare parts, particularly for newer appliance models, poses a significant challenge for repairers. Original parts are often expensive, and disruptions in the supply chain may force repairers to resort to locally-sourced and potentially lower-quality parts. This predicament underscores the importance of streamlining spare parts procurement processes to enhance repair efficiency.

ii. **Navigating skills and training requirements:** Repairers face the challenge of balancing the need to acquire specialised skills for complex repairs, while ensuring manufacturers' requirements regarding intellectual property are protected/addressed. Certification and continuous training are imperative for ensuring repairers stay abreast with repairing diverse appliances and software updates and that manufacturers' reputation with customers is maintained. However, accessibility to such training and certification programmes may be limited, highlighting the need for greater industry support and innovation in this regard.

iii. **Facilitating the disassembly process:** Appliance repairers often rely on spare tool kits provided by manufacturers to facilitate the disassembly process, ensuring safe, efficient, and competent repairs. While most appliances can be dismantled using standard tools, there are instances where specialised equipment is needed. However, access to these specialised tools remains a challenge, hindering repairers' ability to conduct repairs effectively.

iv. **Access to documentation and manuals:** The availability of comprehensive documentation in the form of repair manuals and technical information varies across appliances. While some are accompanied by user manuals, others require repairers to seek out information

themselves. In cases where specialised tools are needed, guidance on acquiring these tools may not be readily accessible, complicating the repair process and prolonging downtime.

v. **Addressing warranty concerns:** Voided warranties present a significant hurdle for repairers and consumers alike, complicating the repair process and diminishing the consumer experience. To foster trust and satisfaction among consumers, manufacturers should strive to streamline the repair process and provide clear guidance on warranty coverages.

vi. **End-of-life considerations:** The concept of energy-as-a-service presents a promising solution to mitigate e-waste by shifting the focus from product ownership to service delivery. By adopting this model, manufacturers can foster a reverse supply chain, in which broken products are promptly replaced, thereby enhancing customer satisfaction. Moreover, prioritising product longevity delivers increased environmental benefits (minimises e-waste), underscoring the significance of sustainable product design and repair practices.

Insights from Literature Review

Of over 150 million solar energy kits sold throughout Africa since 2010, nearly 110 million are estimated to have ceased to function,[41] presenting a significant challenge for the sustainability of the off-grid solar sector. Of these products, 89% were still kept in households, despite the cost of repair being about 31% of the cost of replacement for solar energy kits. Through SolarAid's repair project in Zambia, technicians were able to repair 91.3% of non-functioning solar products, demonstrating that extending the life of most of these products was relatively straightforward when the necessary knowledge, skills, spare parts, and tools were available.

Across important markets for solar appliances in Africa and South Asia, appliance consumers frequently repurpose, adapt, reconfigure, and customise their appliances, either by themselves or by seeking out someone to do this for them.[42] Meanwhile, most solar appliance companies incorporate anti-tampering features, such as proprietary hardware ecosystems and black-box technologies into their appliance designs as a way to ensure appliance quality; however, this feature can often make the appliances less repairable.[43] The GOGLA Connect Initiative[44] is striving to standardise connectors and improve overall interoperability and modularity for appliances, which would also contribute towards improved repairability.

[41] Off-grid solar repair in Africa: from burden to opportunity | SolarAid (solaraid.org)
[42] Murray, D.R., 2020. Fixing development: breakdown, repair and disposal in Kenya's off-grid solar market (ed.ac.uk)
[43] Article: Towards a repair research agenda for off-grid solar e-waste in the Global South
[44] Paper: The Connect White Paper (GOGLA)

Photo caption: Repair Technician Brian Nongo, Zambia. Photo: SolarAid/Jamil Banda (Photo Credit: SolarAid Repair Whitepaper)

Off-grid solar customers prefer to take their faulty appliances to the distributor or manufacturer within the warranty period, typically two to five years for solar water pumps (SWPs)[45] and one year for fans. Outside of the warranty period, customers prefer to take their appliances to local repair technicians.[46]

Appliances with longer warranty and guarantee periods would stimulate higher consumer confidence in their quality and durability, leading to improved customer retention. Additionally, the ease with which customers can access/utilise this warranty and guarantee provisions influences the repairability of a given appliance.

Most e-waste collection centres are in urban areas and cities, whereas most users of solar appliances are located in rural areas, making such services inaccessible for those most in need. According to findings from the Global LEAP Solar E-Waste Challenge, the biggest barrier to take-back schemes is their cost, with the set-up cost of a collection point ranging from US$20 to US$2,000 depending on the design.[47] Several recommendations have been proposed to mitigate this, including leveraging existing distribution infrastructure for take-back schemes and having brand-agnostic schemes where possible. Solar market segments in Kenya include rural consumers (who use domestic solar energy kits), and urban consumers (factories, shopping centres, petrol stations, hotels) who have installed solar panels on their roofs.[48] Due to limited local production of solar product components, the market heavily relies upon imported technology.

[45] Futurepump offers ten years of warranty
[46] mecs.org.uk/wp-content/uploads/2023/07/MECS-EoL-Study-Report_Kenya.pdf pg36
[47] Clasp_EforA-SolarEWaste_5-May.pdf (storage.googleapis.com)
[48] Article: The solar repair trade in Nairobi (Kenya): the blind spots of a "sustainable" electricity policy

Photo caption: E-waste at an appliance repair workshop in Nairobi (Ngara Market), Kenya

In India, the fan market is dominated by local brands that are not all quality verified. Sixty nine percent of households own fans due to affordable prices and the country's humid climate.[49] While it takes specialised skills and knowledge to repair solar appliances, most appliances in India are often easy to repair and technicians are widely available. In addition, purchase of these appliances is heavily subsidised by the government, allowing consumers get them at almost zero cost. However, should the appliance have a fault that needs repair, consumers are reluctant to spend money to get the repairs done.

[49] Country Profile: Off- and Weak-Grid Solar Appliance Market - India

Insights from Existing Regulation

Quantifiable assessments, like **the European Standard for the assessment of repairability, reusability, and upgradeability**, have introduced steps for increasing the sustainability of electronic and electrical products.[50] The right to repair has been recognised in many countries across the globe, including the United States, the United Kingdom, and European Union (EU). In the United States, the Federal Trade Commission directed manufacturers to remedy unfair anti-competitive practices and make sure that consumers can make repairs, either themselves or via third parties. Recently, the United Kingdom passed a law that mandates that all electronic appliance manufacturers ensure that spare parts are available to consumers to get repairs done, either themselves or by local repair shops. In Australia, repair cafes are a remarkable feature of the Australian system. Although not all countries have "Right to Repair" regulation[51] in place, best practices and sustainability principles favor repair over replacement.

Under the **European Commission's Consumer Rights Directive (2011/83/EC)[52]**, the final seller is liable for an appliance for a period of two years. However, the consumer needs to prove that there was a defect or weak component at the time of the purchase after the first six months. Some labels, like the Nordic Swan[53] and European Ecolabel[54], mandate an extra year of warranty at no cost for the consumer.

The Nordic Swan label guarantees that the appliance will work from the day it's delivered, while the **European Ecolabel's** guarantee starts from the purchase date. Both include a service agreement with pickup and return options. These guarantees do not replace the manufacturer and seller's legal obligations. **The Austrian Technical Rules** recommend that the average lifetime for white goods must be at least ten years and five years for brown goods[55], and that this information be provided on a label available / visible to consumers.

The National Environment Management Authority (NEMA) in Kenya introduced a legislative framework for e-waste, making good e-waste practices legally binding to both producers and consumers. Based on the principles of Extended Producer Responsibility (EPR), the proposed e-waste guidelines address a cross-section of the appliance value chain from manufacturers, importers, and assemblers to large institutional and household consumers, to refurbishers and recyclers. There are provisions in the EPR regulations to ensure that manufacturers take action in their research and development activities to reduce the eventual e-waste burden of their appliances.

In India, a bid to emphasise on the LiFE (Lifestyle for the Environment) movement through sustainable consumption resulted in **the Indian Department of Consumer Affairs** setting up a

[50] Efficiency for Access Coalition. "Pathways to Repair in the Global off-Grid Solar Sector." 2020. https://storage.googleapis.com/e4a-website-assets/Pathways-to-Repair-in-the-Global-Off-Grid-Solar-Sector_final.pdf

[51] European Commission. 2023. Right to repair: Commission introduces new consumer rights for easy and attractive repairs. 22 March. Accessed September 19, 2023. https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1794.

[52] http://data.europa.eu/eli/dir/2011/83/oj

[53] Official Nordic ecolabel (nordic-swan-ecolabel.org)

[54] About the EU Ecolabel (europa.eu)

[55] Brown Goods are relatively light electronic appliances such as computers, radios, audio equipment, and televisions, whereas White goods are large household appliances such as freezers, refrigerators, washing machines, stoves (UK: cookers), and dishwashers. (What are brown goods? Definition and examples - Market Business News)

committee to develop a framework on right to repair. This framework targets farming equipment, mobile phones/tablets, consumer durables, and automobile equipment, with the aims of empowering consumers and appliance buyers in the local market, harmonising trade between the original equipment manufacturers (OEMs), and third-party buyers and sellers, emphasising the development of sustainable consumption of appliances and reducing e-waste.[56]

Next Steps: A Call to Action

To support the development and introduction of a repairability initiative, we propose the following roles:

- **Appliance manufacturers and distributors**: Drive repairability by embedding it as a principle in designing appliances. Increase the availability of and access to spare parts and repair information and support the development of technical skills for repair.
- **Policymakers**: Collaborate to develop and adopt legislation to strengthen the repair ecosystem.
- **Programme implementers, funders, and academia**: Provide leadership and overall sector support. Advocate for the adoption of repair strategies, build the knowledge base, and embed the principles of repair and circular economy in grant-making, technical assistance, capacity building, and other market development initiatives.

Efficiency for Access plans to leverage our extensive networks and partners to enable the establishment of a technical working group to facilitate the development of appliance-specific repair indices for solar water pumps, fans, and refrigerators.

Participation in this working group will be open and voluntary to all stakeholders. Members will contribute to the development of the repair indices for each appliance and will actively contribute to their design, review, and piloting.

Please complete this form if you would like to participate in the technical working group.

[56] Press Information Bureau (pib.gov.in)

Conclusion

Overall, the limited repairability options for solar appliances drives up ownership costs and consumer dissatisfaction, particularly for consumers with low incomes or those who cannot access local repair services. For example, as solar water pumps in India do not have a strong after-sales service system, they take over a week to repair, while diesel pumps are repaired in a day by local mechanics.[57]

To address this challenge, it is crucial to invest in training programmes and infrastructure for the repair of solar appliances. In addition, manufacturers should improve the general repairability of their appliances through improved designs, as well as consumer education on the available options for repair.

Repair offers an untapped collaboration opportunity between appliance manufacturers and distributors that would have multiple positive benefits, including but not limited to:

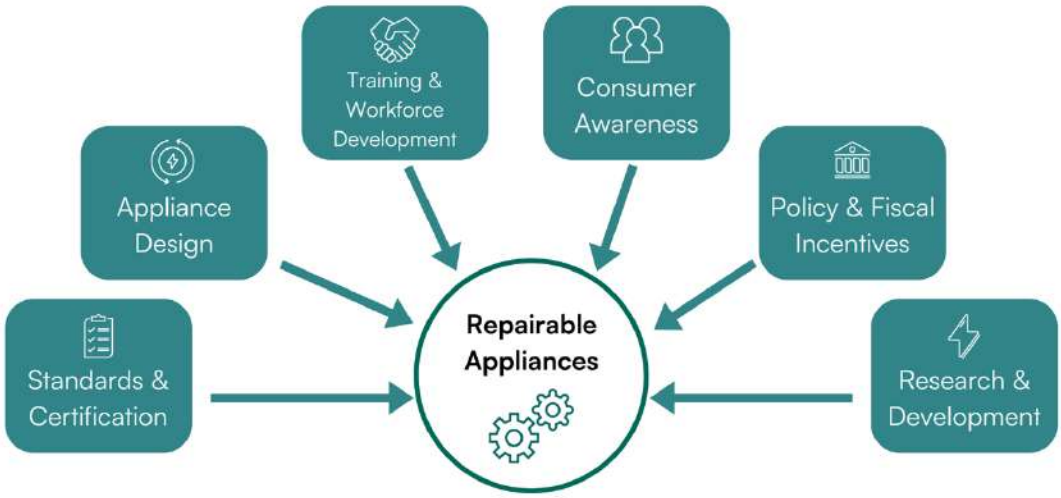
- Enhanced consumer protection by ensuring the ability to use the appliance for the complete lifespan,
- Job creation or enhancement by upskilling informal repairers and expanding the number of repairers who are close to the last mile where appliances are used,
- And reduced e-waste, as there is a need to extend product lifetime and reduce pressure on the limited (formal) recycling infrastructure available.

This paper proposes key criteria for developing a repairability index for solar appliances and is the first of a series. By the end of the series, repair indices for solar water pumps, fans, and refrigerators will be developed in collaboration with stakeholders within the sector. When integrated and implemented together, they are expected to provide a robust pathway to improved repairability for solar appliances, as shown in Figure 8.

An ideal repairability index should incentivise durable appliance designs and reflect regional and appliance-specific nuances.

[57] Report: Impact Assessment of the National Solar Pumps Programme

Figure 8: Pathways to repairability for off-grid solar appliances.



Annexes

Annex 1: Research Methodology

The study assessed appliance repair operations from the perspectives of two distinct groups of individuals: informal repairers and authorised service partners. By considering these target groups, the study ensured that the parameters prioritise the protection of consumer investment by avoiding the loss of warranty through lay person self-repair attempts. The target groups selected were also influenced by the common repair practice in the areas where many solar appliances are sold and used.

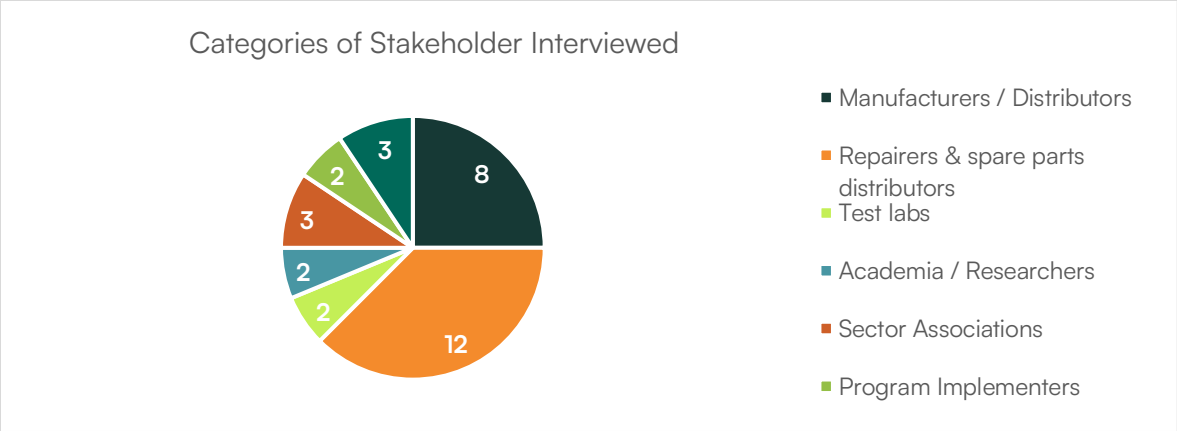
This study employed a mixed methods approach to collect and analyse data, with key data and insights obtained from the sources outlined below:

1. **Desk research:** An extensive review of more than thirty previously published literature sources to gather insights on the repairability and management of solar appliances at their end-of-life.

2. **Key informant interviews:** Expert opinions on key study variables were captured through this process. Interviews were conducted with a diverse pool of over twenty-five knowledge experts from the sector, representing appliance manufacturers and distributors, appliance repairers, academia, programme implementers, and sector associations, as shown in ***Figure 9***. The selection of these experts was informed by their involvement in circularity and appliance repair efforts, as well as previous experience in developing repair scoring systems and standards.

3. **Field surveys:** Additional data was obtained through five field surveys conducted in markets and repair shops in Nairobi (to establish a baseline due to urban skill concentration), with respondents representing appliance distributors and repair technicians. This data was cleaned, analysed, and interpreted to complement the research findings

Figure 9: Categories of Stakeholders Interviewed during the Data Collection Phase (n=32)



Annex 2: Stakeholders consulted

Stakeholder Type	Company/Organisation
Manufacturers / Distributors	Lorentz Futurepump SunCulture Davis & Shirtliff D.light PowerUp Solapodz Engie Energy Access
Academia	University of South Wales University of Minnesota
Appliance Repairers & spare parts distributors	E-waste Initiative Kenya (E-WIK) Revivo WeTu dss+ Evonet Energy Ltd
Sector Associations	GOGLA The Global Distributors Collective (GDC) GOGLA Circularity Working Group
Test labs	Kijani Testing Schatz Energy Research Center
Programme Implementers	Modern Energy Cooking Services (MECS) Program SunnyMoney Zambia/ SolarAid
Regulators & Repair experts	iFixit Europe Environmental Coalition on Standards (ECOS) Tait Consulting
Field Surveys	5 respondents (appliance retailers and repair technicians)

Annex 3: Limitations of Recycling

Efforts to tackle e-waste and create more sustainable appliances and business models have generally focused on an 'end of life' waste reduction strategy. This has involved support for the recycling of appliances and components at their end-of-life. Recycling of e-waste can be a great economic opportunity, as e-waste usually contains various precious metals of high economic value. Such precious metals include gold and silver, which are good conductors of electricity, and germanium, indium, and gallium needed in semiconductor devices.[58] Other materials of value extracted from electrical and electronic equipment (EEE) for recycling include metals (steel, copper, aluminum), glass, and plastics.

There are, however, several downsides to employing recycling as the principal e-waste mitigation strategy. These include:

i. Significant cost implications due to challenges associated with reverse logistics and material recovery processes.

ii. Limited, or non-existent, waste collection infrastructure in key markets for off-grid solar appliances where remote areas are difficult to reach.

iii. Loss of intellectual property, material value, and embodied energy as illustrated by the butterfly diagram of a circular economy. Appliances should be maintained at a high level for as long as possible to make efficient use of the appliances' embodied energy, to avoid a loss of material value, and to retain valuable intellectual property.

iv. Transfer of responsibility from suppliers to local authorities and consumers, despite most of the eventual impact being decided at the design stage of an appliance.

[58] Extraction of Valuable Substances from E-Waste (Onyeje 2014)

Annex 4: Existing Studies on Appliance Repair

In 2020, the Efficiency for Access study on pathways to repair found that the cost of spare parts not otherwise available in off-grid markets, including import taxes/fees, as well as transportation and forex variations, could make repair prohibitive.[59]

A report by McKinsey[60] highlights the suitability of maintenance and repair services for larger appliances due to the high logistics costs associated with refurbishment of these appliance groups. Growth in sustainably produced appliances depends on manufacturers' ability to fully recycle components and materials at scale, from aluminum, plastic, and glass to rare earths, while maintaining their properties and quality. Appliances thus need to be made more repairable from the design stage; for example, appliances need to have stronger eco-design requirements and obtain research and innovation funding, with the aim of reducing the negative environmental impacts of appliances.

These studies provide the research foundation upon which this paper expands.

[59] Efficiency for Access Coalition. 2020. "Pathways to Repair in the Global off-Grid Solar Sector." https://storage.googleapis.com/e4a-website-assets/Pathways-to-Repair-in-the-Global-Off-Grid-Solar-Sector_final.pdf.

[60] Playing offense on circularity can net European consumer goods companies €500 billion | McKinsey

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