PATHWAYS TO REPAIR IN THE GLOBAL OFF-GRID SOLAR SECTOR

OCTOBER 2020

EFFICIENCY FOR ACCESS COALITION &
THE UNIVERSITY OF EDINBURGH

This working paper provides up to date information on repair and repairability in the off-grid solar sector for manufacturers, distributors, energy access policy makers and researchers. It outlines the benefits and barriers to increasing product repairability, examines the applicability of new European standards for the off-grid solar sector, and identifies pathways to repairability.

The working paper was developed by the University of Edinburgh and Efficiency for Access.

Efficiency for Access is a global coalition working to promote high performing appliances that enable access to clean energy for the world's poorest people. It is a catalyst for change, accelerating the growth of off-grid appliance markets to boost incomes, reduce carbon emissions, improve quality of life and support sustainable development.

Efficiency for Access consists of 15 Donor Roundtable Members, 10 Programme Partners, and more than 30 Investor Network members. Current Efficiency for Access Coalition members have programmes and initiatives spanning 44 countries and 22 key technologies. The Efficiency for Access Coalition is coordinated jointly by CLASP, an international appliance energy efficiency and market development specialist not-for-profit organisation, and Energy Saving Trust, which specialises in energy efficiency product verification, data and insight, advice and research.

The University of Edinburgh is a world leading centre for research, teaching and innovation on global energy access.

This working paper was developed by Rowan Spear and Jamie Cross (University of Edinburgh) with Jeremy Tait (Tait Consulting) and Richa Goyal (Energy Saving Trust, Efficiency for Access). It was peer reviewed by Ari Reeves (CLASP), John Keane (SolarAid), Rebecca Rhodes and Drew Corbyn (GOGLA), and Ernestas Oldyrevas (ECOS).

The authors would like to acknowledge and thank Felice Alfieri, Douglas Baguma, Drew Corbyn, Mauro Cordella, Manuel Gollmann, Sarah Hambly, Adrian Honey, John Keane, Paola Manzoni, Greyson Metili, Declan Murray, Ernestas Oldyrevas, Nigel Preston, Ari Reeves, Rebecca Rhodes, Camille Roy, and Chris Spiliotopolos for their support.

This working paper has been funded by UK Research and Innovation, through an Economic and Social Research Council Impact Acceleration Award. The views expressed do not necessarily reflect the UK government's official policies.

Cite as: Spear, Rowan, Cross, Jamie, Tait, Jeremy, Goyal, Richa., 2020. *Pathways to Repair in the Global Off-Grid Solar Sector*, Efficiency for Access

TABLE OF CONTENTS

Repair
The process of returning a faulty product to a condition where it can fulfil its intended use. [1]

Disassembly
The process whereby a product is taken apart in such a way that it could subsequently be reassembled and made operational.[2]

Durability
The ability to function as required, under defined conditions of use, maintenance and repair, until a limiting state is reached (e.g. product state after primary or secondary functions are no longer delivered).[3]

Reliability
The probability that a product functions as required under given conditions, including maintenance, for a given duration without a limiting event (e.g. primary or secondary functions are no longer delivered). [4]

Limiting Event
Occurrence which results in primary or secondary function no longer being delivered.[5]

Product Lifetime
The duration of the period that starts at the moment a product is released for use after manufacture and ends at the moment a product becomes obsolete beyond recovery at product level.[6]

Refurbishment (Reconditioning)
Returning a used product to at least a satisfactory working condition by rebuilding or repairing major components that are close to failure even when there are no reported or apparent faults in those components. [7]

Remanufacture
Returning a used product to at least its original performance with a warranty that is equivalent or better than that of the original product.[8]

Circular Economy
A model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible.[9]

1. European Committee for Electrotechnical Standardisation, 2019 *General methods for the assessment of the ability to repair, reuse and upgrade energy-related products* EN 45554:2020 (E), p7
2. Ibid, p7
3. Ibid, p6
4. Ibid, p7
5. Ibid
6. Den Hollander, M.C., Bakker, C.A., Hultink, E.J., 2017. Product design in a circular economy: development of a typology of key concepts and terms Journal of Industrial Ecology. 21(3), 517e525.
7. Bakker, C., den Hollander, M., Van Hinte, E. and Zijlstra, Y., 2019. Products that Last 2.0: Product Design for Circular Business Models. BIS Publishers. p35
8. Ibid
9. European Parliament, 2015 *Circular Economy: definition, importance and benefits*. Available at: https://tinyurl.com/EUparl2015

PAYG / PAYGO
A business model which allows users to pay for their products via technology, enabling embedded consumer financing. A PAYGO company will typically offer a solar product for which a customer makes a down payment, followed by regular payments for a term ranging from six months to eight years. Payments are usually made via mobile money, though alternative methods include scratch cards, mobile airtime, and cash.[10]

10. Lighting Global, 2020 *Off-grid Solar Market Trends Report March 2020*. Available at: https://tinyurl.com/LightingGlobal2020

1. INTRODUCTION

This working paper sets out to provide evidence on the case for developing and implementing repairability assessment standards for off-grid solar products [11]. The working paper addresses benefits, risks, key issues, and key players, and lays out pathways to justify and inform future work.

Repairability is a manageable and realistic mechanism for product lifetime extension. Quantifiable assessments, like the new European standard for the assessment of repairability, reusability and upgradeability, have introduced new steps for increasing the sustainability of electronic and electrical products. The global off-grid solar sector is presented with an important opportunity to demonstrate its leadership on sustainability, whilst creating more value for consumers and companies.

Over the next decade, the repairability of off-grid products will become increasingly important to policy makers, off-grid companies, and consumers for a range of environmental, business and societal reasons that are set out in this paper.

In some cases, the economic argument for improved repairability in the off-grid solar industry is relatively straightforward. Many PAYGO players, for example, understand that off-grid solar assets which remain in need of repair in the payment period, or which could be refurbished, cost them money – whether in terms of lost revenue, the costs of storage or disposal. Improved repairability creates the potential for these costs to be converted into new business opportunities.

In other cases, the economic case is less straightforward than the wider social and environmental arguments. Increasing the repairability of any electronic or electrical product is increasingly understood to enhance consumer impacts by: extending product lifespans, creating local additional local value through jobs and employment, and further reducing carbon emissions across the value chain.

As industry stakeholders seek to mitigate the risks associated with product disposal at the end of life, it is useful to establish a common approach, terminology and assessment framework for addressing repair.

This working paper is intended to help stakeholders understand the benefits and barriers to increasing repair, to provide a set of parameters and metrics for evaluating the ability to repair products, and to identify policy needs and opportunities that can inform decisions about product design interventions and business models that will extend the lifetime of off-grid products.

SCOPE OF WORK

- To collate evidence on the repairability of priority off-grid products
- To establish the links between the repair economy, livelihoods and skills as well as end of life waste issues, the circular economy, quality assurance, and the achievement of the UN’s Sustainable Development Goals
- To inform policy makers and managers about programmes and initiatives focused on the development and deployment of repairable off-grid products
- To focus attention first on progress with important current products, as a springboard to address other products further up the energy ladder based on market penetration and public visibility, as well as their reliability, cost and relative risk of accidental damage.
- To examine how repair can also be a business strategy in and of itself

11. Off-grid solar products, here, refers to products across the four key categories commonly used in the sector: solar lanterns, SHS kits, appliances and productive use.

METHODOLOGY

This working paper was compiled based on a review of current research, evidence and new standards for repairability. The working paper draws on reports and research published by key stakeholders as well as independent academic research published in international, peer reviewed journals.

The working paper also includes a systematic analysis of the applicability to the global off-grid solar sector of a new European Standard (EN 45554:2020) for the assessment of repairability, reusability and upgradeability of energy related products. This European Standard represents a significant tool for eco-design and electronic waste management. The standard defines parameters and methods that can be used to assess the ability to repair, reuse and upgrade products. This working paper considers the applicability of this new European standard and the specific challenges around the availability of spare parts and repair information to consumers in off-grid markets.

The working paper provides a definition and typology of repair in order to facilitate future discussion and assist the incorporation of repairability into future product designs, partnerships and programmes.

This working paper includes input from a range of stakeholders across the sector, as well as interviews with the lead authors of the European Standard.[12]

12. Stakeholders include representatives of: GOGLA, CLASP, Total, Azuri, SolarAid, Mango Solar, Innovex, Lorentz, Engie, IOM, UNHCR Innovation Service, GTZ, ECOS, and the Joint Research Centre.

Market research indicates that around 180 million off-grid solar units have been sold worldwide since 2010, comprising 150 million pico-solar products and 30 million solar home systems. According to Lighting Global, if we account for the anticipated lifecycle of these products just under half of this total (or approximately 84 million units) was still 'live' or 'in use' by 2020.[13] But what will happen to the remaining 66 million units that are no longer 'in use' before they find their way into electronic waste flows?

Over the past three years action on sustainable e-waste management in the global off-grid solar sector has accelerated. Whilst still representing a fraction of total electronic waste volumes, e-waste from off-grid solar products and systems is set to grow exponentially in the very parts of the world that are currently least able to process it.[14] As we examine below (See Chapter 3), whilst lessons can and must be transferred from the treatment of e-waste in other economies, there are exceptional opportunities for business and societal benefits from repairability in off-grid communities. Key enablers such as low cost of labour, an insufficient supply of products to meet demand and the injection of substantial development partner support arguably make a circular economy approach here more achievable than for its retrofit onto established product economies. It is also more urgent to act in order to influence and shape this market at a time of potential growth when a radically different approach can most easily be embedded in economically viable ways.

The visibility and sustainability credentials of off-grid solar make successful e-waste management particularly important for the sector's future. There is increased interest in the principles and prospects for repairability, for example, amongst members of GOGLA, the largest industry body serving the sector. As we argue here, directly engaging with repairability offers the sector a new opportunity to demonstrate its leadership on e-waste and the circular economy.

The imperatives for business action on repair are similar to those for acting on e-waste. It will prepare the sector for future regulatory initiatives; it will pre-empt the interest of investors in the circular economy; and it will mitigate the potential risk to brand names as individual and institutional consumers, as well as governments and investors, become increasingly concerned about product lifetimes and planned obsolescence across electronics industries. At the same time, it presents a major opportunity to strengthen the eco-credentials of off-grid solar companies.

CURRENT SECTOR-WIDE INITIATIVES

Sector-wide initiatives on e-waste signal a commitment to engaging with sustainability issues and to supporting responsible e-waste management. GOGLA has led sector-wide action through the convening of industry practitioners at regular circularity working group meetings; and the development of an e-waste toolkit for manufacturers and distributors .[15] In East Africa, these efforts have laid the ground for new collaboration. The Kenya Solar Waste Collective, for example, aims to develop a common strategy around the joint take-back of solar e-waste. The collective aims to support future collaborations around the collection of products, pricing structures for e-waste handling, recycling and disposal; consumer awareness raising on end-of-life and out of warranty solar e-waste; industry-wide training on the collection, handling and transportation of solar e-waste; the development of standardised metrics for scoring recycler audits, data collection and reporting; as well as take-back and collection models.

13. Lighting Global 2020 *The 2020 Global Off-grid Solar Market Trends Report*, p6
14. Hansen, U.E., Nygaard, I. and Dal Maso, M., 2020. The dark side of the sun: solar e-waste and environmental upgrading in the off-grid solar PV value chain. Industry and Innovation, pp.1-21.
15. See: https://www.gogla.org/e-waste

Meanwhile, international aid and development donors have made repairability a key component of new funding programmes and e-waste initiatives. In East Africa, the Solar E-waste Challenge has catalysed efforts to collaborate between manufacturers and last-mile distributors. One such example of recent efforts is the Kenya Solar E-Waste Collective, an open group of companies that are exploring ways to coordinate on areas such as consumer take-back schemes, raising consumer awareness, supply chain efficiencies and partnerships, and training provision for staff and agents within the sector. The Kenya Solar E-Waste Collective was established to increase collaborative action on e-waste management in order to improve market conditions for all.

Prominent distributors in sub-Saharan Africa and South Asia - SunnyMoney and Frontier Markets - endorsed the off-grid Solar Scorecard, an online tool that systematically reviews and rates the repairability of pico-solar products.[16] USAID and UK aid have supported action through the Global LEAP Solar E-Waste Challenge[17] that set out to catalyse research and development into more sustainable off-grid solar products and business models. The German Development Agency, GIZ, has been developing concepts for off-grid waste management and the circular economy in East Africa, supporting the development of guidance documents and facilitating stakeholder meetings.[18] A pilot project funded by Innovation Norway in collaboration with the International Organisation for Migration is also focusing attention on repair as a driver of social, economic and environmental benefits in humanitarian energy markets.[19] This pilot aims to support existing repair businesses in displacement settings with training and access to spare parts, as a means of increasing incomes and decreasing the costs incurred by displaced people to keep their solar lighting products in use for longer.

These initiatives all recognise that approaches to e-waste management - ranging from product take-back programs to repair, refurbishment and recycling - provide industry with new opportunities to optimise business models and deliver on the UN's Sustainable Development Goals.[20]

Recommendations and best practices for future action on sustainable e-waste management all emphasise the need to embed recyclability and repairability into the design of solar home system components, and to utilise informal sector partnerships on repair and product collection at the end of life.[21]

REPAIR AND THE CIRCULAR ECONOMY

To date, strategies for market growth and energy access in the global off-grid solar sector have been largely premised on the logic of conventional, linear economies.[22] Over the past thirty years, alternative systems have emerged for describing and designing more sustainable economies.[23] Today, there is a new consensus around the idea of a circular economy.

In a circular economy, the ability to repair (or to maintain and prolong the life of a product) is the highest value material loop, situated before refurbishment and recycling.[24] Repair is widely understood as the cornerstone of any future 'circular off-grid economy': a product lifetime extension strategy that is capable of delivering significant social, economic and environmental impact.

16. See, http://www.offgridsolarscorecard.com
17. See: https://globalleapawards.org/e-waste
18. Further details about the GIZ project are available at: https://www.giz.de/en/worldwide/15109.html
19. Further details about the Innovation Norway/IOM project are available at: https://tinyurl.com/NorwayIOM
20. Efficiency for Access 2019 Sustainable E-Waste Management Practices for the Off-grid Sector: Workshop Report.
21. ibid, p5
22. Staub, L., 2019. *Off-grid Solar Products Going Circular: Exploring the potential for repair, refurbishment and remanufacturing strategies and business models for Solar Home Systems and Solar Lanterns in India*. IIIEE Master Thesis.
23. Ehrenfeld, J. R., 1997. *Industrial ecology: a framework for product and process design*. Journal of cleaner production, 5(1-2), pp.87-95.
24. Ellen MacArthur Foundation 2015. *Growth Within: A Circular Economy Vision for a Competitive Europe*. https://tinyurl.com/y5daudmb

Repair is important because it:

- Conserves embodied energy, materials, and water.[25]
- Facilitates the reuse of components, making more efficient use of scarce materials
- Reduces the transportation costs required to put products back into use by supporting local repair solutions.[26]
- Minimises the loss of materials and energy represented by the production of waste.
- Generates jobs to service repairs.[27]
- Generates additional economic revenue from the original product.

There is new interest in adapting the global off-grid solar sector around circular business models, backed up by persuasive arguments that this is an easier 'win' in emerging off-grid energy markets than in longer-established ones (see Chapter 2).

At the same time, there is increased interest in designing off-grid solar products specifically for the circular economy, as evidenced by research and development initiatives at universities across the United Kingdom, the Netherlands and Germany.

These projects are focused on the technical and commercial challenge of producing a new generation of repairable devices for circular economies in sub-Saharan Africa and South Asia. Some, like the University of Edinburgh's award-winning, open-source lamp and charger, Solar What?!, were built specifically to promote circular design thinking and to catalyse debate about what this might mean for the sector.[28] Other projects have given rise to new start-up companies (see Case Study 1).

REPAIR AND OFF-GRID MARKETS

Globally, global markets for repair services related to personal and household goods are expected to grow from $133.8 billion in 2019 to $167.2 billion in 2020.[29] In sub-Saharan Africa and South Asia, where the repair of electronic products is already a common feature of everyday life and economic activity, markets for the repair and maintenance of personal/household goods are growing, driven by demand for electronics and communication technology.[30]

Across important markets for off-grid solar in sub-Saharan Africa and South Asia, product users frequently repurpose, adapt, reconfigure and customise products, either by themselves or by seeking out someone to do this for them.[31] Repair is what happens when people seek to return an off-grid product that is faulty or broken to a condition of basic functionality that allows it to fulfil its intended use.

The act of repair demands to be understood in a positive sense. When a product user in rural India or Kenya seeks out a repair service, they are making an intentional effort to extend the lifespan of a product, and demonstrating the continued value of that product for them.[32]

Off-grid solar companies increasingly offer in house repair services for in-warranty products. Indeed, evidence suggests that first-time users sometimes view a lack of access to after-sales repair services as a barrier to new purchases of off-grid products.[33] However, last mile consumers are not always able to avail these in-house services. Returning products to a vendor can come at a

25. Ellen MacArthur Foundation 2016 *Empowering Repair.* https://tinyurl.com/y2xp5gj5
26. ibid, p5
27. ibid, p5
28. See: www.solarwhat.xyz
29. Research and Markets 2020 *Personal & Household Goods Repair & Maintenance Revenues World Report & Database* Datagroup Booksellers
30. Cross, J. and Murray, D., 2018. The afterlives of solar power: Waste and repair off the grid in Kenya. *Energy research & social science*, 44, pp.100-109; Kumar, A. and Turner, B., 2020. Sociomaterial solar waste: afterlives and lives after of small solar. In *Energy Justice Across Borders* (pp. 155-173). Springer, Cham.
31. Murray, D.R., 2020. *Fixing development: breakdown, repair and disposal in Kenya's off-grid solar market*. PhD Thesis submitted to the University of Edinburgh; Samarakoon, S., 2020. The troubled path to ending darkness: Energy injustice encounters in Malawi's off-grid solar market. *Energy Research & Social Science,* 69, p.101712;
32. Houston, L., Jackson, S.J., Rosner, D.K., Ahmed, S.I., Young, M. and Kang, L., 2016, May. Values in repair. In *Proceedings of the 2016 CHI conference on human factors in computing systems* (pp.1403-1414).
33. Kundu, A. and Ramdas, K., 2019. *Timely After-Sales Service and Technology Adoption: Evidence from the Off-Grid Solar Market in Uganda*. SSRN 3477210.

cost (either in lost productivity or wages, or in transport costs between the points of use and point of sale). Users with in-warranty products sometimes seek out other repair services and, when a warranty expires, the responsibility for repair is effectively transferred to them. Academic and independent research studies show that across off-grid solar markets in sub-Saharan Africa and South Asia, people are more than willing to seek out third-party repair service providers and pay for repair work. This applies both to out-of-warranty products as well as in-warranty products, particularly in contexts where the costs of time and travel involved in returning products to a vendor may appear higher than third party repair.

Most common requests for electrical repairs involve broken wires or electrical components; and requests to modify charging plugs, connectors and cables. These informal, third-party repair economies are often self-trained in repairing solar products and operate off the grid, without electricity. Repairs on microelectronic components and printed circuit boards, for example, are frequently attempted with little more than screwdrivers or homemade soldering irons.

Some repairs are attempted or undertaken by consumers themselves. These repairs demand to be understood as a form of user-innovation. This is what happens when people see limitations in the design or suitability of a technology and seek to make improvements themselves, by fixing it for use.

Recent independent research studies on the off-grid solar sector emphasise the significance of repair:

- A large scale survey of 1082 households in Odisha, India conducted in 2017 found that 26% of all solar energy systems currently in respondent's homes (including 531 pico-solar lighting kits and 492 solar home systems) were deemed to be broken by their users, and that people travelled over an average of 20 kilometres in search of repair services.[34]
- A qualitative survey of energy access in two refugee camps in Burkina Faso and Kenya showed that repair was a central rather than a peripheral part of refugee economies. The research showed that third-party repair services for pico-solar devices were thriving, creating informal livelihood opportunities for refugees and host communities.[35] These repair economies connect refugee and host communities. Flows of spare parts and components into refugee camps completely bypass humanitarian agencies and energy companies, depend on individual links and access to market suppliers in towns and cities.
- A small-scale study of 114 people carried out by SunnyMoney in Zambia in 2020 showed that, on average, 43% of people who owned a solar light had attempted repair either themselves or through a local technician.[36]

REPAIR AND COVID-19

The global COVID-19 pandemic is having a clear impact on off-grid solar markets.

A survey by Sustainable Energy for All reported widespread disruption in the supply chains for spare parts and support activity as a result of the pandemic.[37] Meanwhile, lockdowns and social distancing measures introduced to prevent the community transmission of COVID-19 will force solar companies to reconsider how they provide after-sales services to their customers

Around the world, the COVID-19 pandemic has thrust repair into the spotlight. The ability to repair essential equipment has proven to be as important to healthcare providers, for example, as the procurement of new technologies.[38]

34. Batti Ghar Foundation, 2017 *Understanding Energy Access in Rural India*. Odisha: Bhubaneswar. https://tinyurl.com/EnergyAccessOdisha2017
35. Cross, J., Douglas, M., Grafham, O., Lahn, G., Martin, C., Ray, C. and Verhoeven, A2019. *Energy and Displacement in Eight Objects: Insights from Sub-Saharan Africa.* London: Chatham House.
36. Solar Aid, 2020 *Everyone Deserves the Right to Repair.* www.solar-aid.org/everyone-deserves-the-right-to-repair/
37. See: https://www.seforall.org/news/supporting-the-global-fight-against-covid-19
38. See: https://therestartproject.org/news/prepare-to-repair-covid-19/

Meanwhile, there is a resurgence of interest in repair from consumers, as they seek to save costs by fixing what they have rather than investing in new technologies. [39]

Some argue that repair should be an essential part of strategies for pandemic preparedness, with the ability to repair products helping to build resilience to future supply chain and economic shocks.[40]

Investments in a green recovery from COVID-19 present an opportunity to put repair and repairability centre stage, as national governments seek to boost local economies and employment through the local manufacturing of essential technologies, spare parts and components.

39. See: https://www.theguardian.com/technology/2020/apr/15/the-right-to-repair-planned-obsolescence-electronic-waste-mountain/
40. See: https://www.wired.com/story/opinion-the-right-to-repair-will-help-us-endure-outbreaks/

Since the 1980s, virtually all electrical household appliances have become less repairable, and this is also true for off-grid products.[41] But designing for repair and repairability has benefits for the economy, society and the environment.[42]

Resources produced by Lighting Global and GOGLA acknowledge the potential benefits of repair for the off-grid sector.[43]

This chapter of the working paper adopts an approach taken by the European Parliament to analyse the specific challenges and opportunities for repair of off-grid solar products.

We have disaggregated the benefits and impacts of increased repair rates for manufacturers and product users (see Table 1 below).

Of course, not all manufacturers and distributors share the same view. Different perspectives across the sector arise from specific market conditions and contexts in which companies operate, their business strategies and investments, as well as their market experience.

However, the benefits and impacts lessons identified here highlight key opportunities for policy and product design that can readily be applied to the off-grid solar sector. They are linked to livelihoods, jobs and skill development as well as to end-of-life waste issues, the circular economy and quality assurance - which underpin many of the UN's Sustainable Development Goals.

Table 1: Benefits of Repair Overview

	PRODUCT USERS	MANUFACTURERS AND DISTRIBUTORS*
Economic Benefits	• Price savings • Livelihoods: jobs and revenue	• Reduced overheads • Resource efficiencies • Increased trust • Retention of value and intellectual property • Communication efficiencies • Higher value components and materials for recyclers • Extended customer relationships • Reduced need for legislative action
Environmental Benefits	• Reduction in CO2 emissions • Reduction in e-waste volumes	• Reuse of valuable materials • Reduction in CO2 emissions • Reduction in e-waste volumes
Societal Benefits	• Energy access • Trust in off-grid technology • Livelihoods • Social relationships	• Energy access • Trust in off-grid technology

*Not all benefits are directly relevant to specialist distribution companies

41. Research from the Öko-Institut has shown that product life spans are getting progressively shorter, see Prakash S. e.a. 2016, *Einfluss der Nutzungsdauer von Produkten auf ihre Umweltwirkung: Schaffung einer Informationsgrundlage und Entwicklung von Strategien gegen* „Obsoleszenz UBA Texte https://tinyurl.com/y8u7pfgz (in German)
42. Charter, M. ed., 2018. *Designing for the circular economy*. London: Routledge; Cooper, T. and Salvia, G. 2018 "Fix it: barriers to repair and opportunities for change." In R. Crocker and K. Chiveralls (eds) *Subverting consumerism: reuse in an accelerated world*. Abingdon: Routledge. p5.
43. Lighting Global 2015 Eco Design Note 2; GOGLA 2019 E-Waste Toolkit - Module 2 Briefing Note

ECONOMIC BENEFITS

Price savings

For most users, the cost of repairing a product should be cheaper than buying an identical replacement. Access to repair enables users to extend the useful lifetime of an off-grid product and ensures continued access to basic energy services. Even if a broken product is out of warranty, repair should also offer a cheaper alternative to purchasing a replacement and extends the return on their initial outlay or investment.[44] Some companies are demonstrating this 'in-house', by refurbishing stock and offering these products as a cheaper alternative for low-income consumers.

The goals of most off-grid solar companies should identify these savings as a critical part of pathways to sustainability and energy access. People who would struggle to afford a new product may be able to pay for it to be repaired, saving themselves money and extending the return on their initial investment, whilst retaining their access to energy. In addition, the longer the useful lifetime of an off-grid solar product, the more money a user can save compared to the purchase of batteries, kerosene or candles. For some companies, like those selling PAYG systems, enhanced repair ensures a continued revenue stream from customers: a product that is out of action represents lost income and customer dissatisfaction. If a product can be repaired in-situ, and quickly, all the better.

Job creation and livelihoods

The current lack of personnel to service and repair off-grid lighting products represents both a potential barrier and an opportunity.[45] Across the off-grid solar sector's key national markets in South Asia and sub-Saharan Africa, products are repaired by third-party technicians operating in the informal economy. These may include technicians with no formalised or certified training, as well as people who have received secondary school level or vocational training qualifications. Third-party repair technicians learn on the job through trial and error and often pass on their knowledge and skills to others (including their children). Repair services are often provided at the very local level. In many informal economies, repair supports local livelihoods and household incomes through the provision of a basic income. Increased support for repairability would likely result in a corresponding increase in repair related local employment. This is also true in formal job markets where manufacturers and distributors can leverage the opportunities that repair and refurbishing models present to their business; upskilling their technical agents.

Reduced overheads

In many cases, the argument for improved repairability ought to be relatively straightforward. Many PAYGO players in the sector, for example, understand that off-grid solar assets which remain in need of repair or which could be refurbished cost them money - whether in terms of lost revenue or costs of recovery, storage, maintenance and replacement- and present a risk to brand reputation or perception. The economic argument for repairability is probably easiest to make for solar home systems as this is where the economic benefits for customers and companies are most easily demonstrated. However, the societal and environmental arguments for repairability apply across the full range of off-grid solar systems.

Resource efficiencies and cost mitigation

By designing and supporting products which are easy to repair, off-grid solar companies can save resources (time, energy and materials) compared to either a more linear 'take, make, use, lose'[46] strategy or an approach to e-waste mitigation which solely favours recycling.[47]

44. Energy Africa, Evidence on Demand, Cyrcle Consulting, Sofies 2016. *Energy Africa 2016 Electronic Waste (E-Waste) Impacts and Mitigation Options In The Off-Grid Renewable Energy Sector* p.34. https://tinyurl.com/SOFIES2016
45. Scott, Inara. "A business model for success: Enterprises serving the base of the pyramid with off-grid solar lighting." *Renewable and Sustainable Energy Reviews* 70 (2017): pp.50-55.
46. E.g. Raworth, K., 2017. *Doughnut economics: seven ways to think like a 21st-century economist*. London: Chelsea Green Publishing.
47. UNEP 2017. *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*, p.17. http://tinyurl.UNEP2017

Retention of embedded value
Repairable products are easy to disassemble either in-house or by third parties. This allows for the reuse of components and keeps the embedded value of products and components – value that originates from their design, manufacture, assembly, transportation and distribution – in circulation.[48]

Communication efficiencies
Facilitating in-house repair makes it easy to diagnose and act on common product failure points, generating further competitive advantages via the increased ability to identify, during the repair process, recurring points of failure- information which can then be fed back into the design and production processes.[49]

Higher value components and materials for recyclers
An increased ease of disassembly improves the economic incentive to recycle end-of-life products and components. Time can be saved in separating materials into the appropriate processing streams and, as more materials can be separated out, the 'waste' has a higher value.[50]

Extended customer relationships
Increased repairability offers a competitive edge for companies. It creates opportunities for companies to establish extended relationships with customers through increased touchpoints, such as in a repair shop. These touchpoints can be used to reacquaint the customer with a brand and demonstrate, and sell, additional products and services. This model not only offers increased support for in-warranty products requiring repair or replacement, but also offers a further revenue stream through the sale of spare parts and repair services to customers with post-warranty products.

Reduced need for legislative action
A self-regulating and responsible industry is proactive rather than reactive. It can avoid more punitive policy measures such as extended producer responsibility, and waste levies, and is better placed to engage in the drafting of future legislation.[51]

ENVIRONMENTAL BENEFITS

Reuse of valuable materials
As electrical and electronic goods, it is especially important to design off-grid solar products which are durable and repairable. [52] The inherent material complexity of these products results in challenges both at the end of the products' (or components') useful life and in the sourcing of the materials used in their creation; many of the key materials being environmentally harmful to extract.[53] All off-grid solar products contain rare earth elements which have significant negative environmental impacts related to their extraction and refinement.[54]

Recovery of these materials is technically and logistically challenging, particularly in countries where waste collection infrastructures are underdeveloped and where products are sold in remote areas.[55] Repair extends the useful life of materials, helping to mitigate the negative environmental impact incurred further upstream.

48. GOGLA 2019 *E Waste Module Briefing 2* https://tinyurl.com/y2bu2uxt p.8.
49. European Union 2018 *The Route to a Circular Economy*. https://tinyurl.com/yy6d9vyb p15.
50. Vanegas, P., Peeters, J.R., Cattrysse, D., Tecchio, P., Ardente, F., Mathieux, F., Dewulf, W. and Duflou, J.R., 2018. *Ease of disassembly of products to support circular economy strategies*. Resources, Conservation and Recycling, 135, pp.323-334.
51. Lighting Global 2017 *Repair Guide Econotes 7*. https://tinyurl.com/yyh53mpv p6.
52. European Commission 2015 *Closing the Loop : An EU Action Plan for the Circular Economy*. https://tinyurl.com/y6f58cus (section 1.1)
53. Lobus, A., (2017) *Mending broken promises in sustainable design* in Chapman (Eds) Routledge Handbook of Sustainable Product Design. London: Routledge
54. GDSR 2015 *Rare Earth Elements: From Mineral to Magnet*. https://tinyurl.com/y2vvxvfq p2.
55. Shin, S.H., Kim, H.O. and Rim, K.T., 2019. *Worker Safety in the Rare Earth Elements Recycling Process from the Review of Toxicity and Issues*. Safety and Health at Work, 10(4), pp.409-419.

From a product user's perspective, this is important. In current off-grid markets, the environmental benefits are often viewed as less significant than economic benefits to product users. However, it remains to be seen how national level debates about the environmental impact of new technologies – including increased mineral flows and electronic waste – will impact the solar industry.

Reduction in manufacturing pollution, and in water and energy usage
The manufacture of new products requires energy and water. It emits environmental pollutants either directly, as part of the manufacturing process, or indirectly via the production of energy. These factors differ significantly depending on the type of manufacturing process, the raw material used (for example virgin versus recycled materials), and method of energy production. Increased repairability extends product lifetimes, maintaining existing components and materials at a high value level. It reduces the demand for more energy, water and pollutant intensive manufacturing processes and refocuses it on repair, refurbishment and remanufacture.[56]

Reduction in CO2 emissions
The extension of product and component lifetimes through repair also has the potential to generate lower carbon dioxide emissions when compared to the manufacture of replacements.[57] Of course, this will not be universally true of all replacements. For example, replacement products that provide significant improvements in energy efficiency with less embedded energy may bring about greater emissions reductions. Understanding the potential for increased repairability to reduce CO2 emissions in existing product lines requires a thorough, product by product life-cycle analysis. If the aim is to significantly reduce CO2 emissions in future off-grid solar product lines, however, from an emissions reductions perspective there is little reason not to design for repairability.

Reduction in E-Waste Volumes
Increased repairability presents an opportunity to keep products and components in use for as long as possible. This reduces overall e-waste volumes by reducing upstream material consumption and preventing premature downstream disposal, and reduces the negative health and environmental impacts associated with improper e-waste management.

56. Montalvo, C., Peck, D. and Rietveld, E. 2016 *A Longer Lifetime for Products: Benefits for Consumers and Companies*. European Parliament Directorate General for Internal Policies, pp.41–42. https://tinyurl.com/y5axrmgo
57. BSI (British Standards Institution), 2012. BS 8887-211:2012 *Design for manufacture, assembly, disassembly and end-of-life processing (MADE) Specification for reworking and remarketing of computing hardware*, London: BSI

SOCIETAL BENEFITS

Energy access
The longer the useful lifetime of an off-grid solar product, the more the user can benefit from the energy access features of the device- be it lighting, connectivity, cooling, or entertainment. A higher standard of living is both maintained and maintainable.

Trust in off-grid technology
Commitment to, and demonstrations of, product repairability can help to establish trust in off-grid solar technologies.[58] Manufacturers, distributors and product users benefit from products which are long-lasting and reliable. Products with these attributes are trusted and valued in an off-grid context.[59]

Value in repair work
Repair work generates both social and economic value. Making a living through repair allows people to demonstrate that they are skilled, manual practitioners. Around the world, repair work is frequently associated with specific places, cultural histories and gender norms. In many places, repair work is an important expression of identity, heritage and personal competence.

Social relationships
Repair work is not always monetised. In many informal economies repair is frequently provided as a free service by third-party providers, small scale or micro- entrepreneurs to people within their social networks or as a gift across kinship and friendship groups. Repair is important for maintaining relationships between users, and between users and solar companies.

58. Lighting Global 2017 *EcoDesign Notes 7*, Repair Guide. p.6.
59. See: https://verasol.org/solutions/certification

CASE STUDY 1: MANGO SOLAR

Mango Solar is a start-up off-grid solar company that uses a twofold approach in its B2B business model. They manufacture IoT-enabled solar home systems and develop software solutions for last-mile distributors in rural Africa. Since many of the company's products are enabled for leasing, product longevity was an important consideration from the outset.

Mango Solar's commitments to building products that are "made to last" have seen them take a proactive approach. Their product design process has focused on repairability as a strategy for reducing waste and increasing their positive environmental impact. The company aims to build products that can be repaired easily and fast if something fails. To this end, they have developed solar systems that are repairable by design by factoring in local assembly, ease of disassembly, and fully replaceable components.

Local assembly

Mango Solar's products are designed to be very easy to assemble and, wherever possible, include features to prevent parts from being assembled the wrong way. The products are designed to be assembled locally in Kenya to increase social impact and reduce the carbon footprint. At the same time, this local capacity and knowledge building can facilitate local repairability. This enables higher flexibility and speed to customer inquiries like providing samples or repair and replacement services.

Designed for disassembly

The core product - "mango Combo" - is a combination of a power bank and a torch. It has an internal frame on which all components are mounted, such as the battery, the printed circuit boards and other internal mechanical parts like the sealing rubber strips. Once everything is mounted on the internal frame, the module is just pushed into the casing. In case something needs to be repaired, the inner part can just be slid out again for accessibility. In general, all parts can be disassembled easily, since no glue is used, and parts are either clipped or screwed. Furthermore, all outlets are sealed so that the whole system is water and dust proof. All products come with a 5-year warranty.

Replaceable battery

The battery is connected via a pin header, allowing for easy replacement in case of failure or age-related performance drops. Batteries are the components that usually break the fastest. Apart from standard protections from events like overcharge and deep-discharge, Mango Solar has implemented a charging algorithm to extend the battery lifetime.

Image: Mango Solar's "mango Combo" product in situ

SIDE NOTE: DOWNSIDES OF AN 'END OF LIFE' WASTE REDUCTION STRATEGY

The global off-grid solar sector, in its efforts to tackle e-waste and create more sustainable products and business models, has focused considerable effort on an 'end of life' waste reduction strategy. This has involved support for the recycling of products and components at the end-of-life.[60] Recycling offers an important means to recover valuable materials and avoid environmental contamination through improper disposal. There are, however, several downsides to employing it as the sole or principal e-waste mitigation strategy.

Cost implications

There are significant cost implications associated with recycling. Any recycling strategy involves a challenge in reverse logistics. This challenge is amplified in key markets for off-grid solar products such as sub-Saharan Africa, where waste collection infrastructure is limited, or non-existent and remote areas are difficult to reach.

Products that companies have expended so much effort in distributing to 'last-mile' and 'hard to reach' customers must make the same return journey to a centralised recycling centre. Once collected, e-waste rarely goes direct to recycling facilities but must be stored, incurring additional storage costs. Additionally, solar products are materially complex and require careful disassembly, sorting and storing before they are recycled.[61] The relatively small volumes of e-waste collected by most off-grid companies results in a high unit price paid to recyclers. The core components of off-grid solar products, such as batteries and photovoltaics, need specialist facilities to be appropriately and fully recycled. An effective recycling strategy needs to fund these activities and the associated infrastructure.

Loss of value and embodied energy

Recycling results in a loss of intellectual property, material value and embodied energy. As materials become parts, components and ultimately products, value is accrued, intellectual property is generated, and energy is expended. The butterfly diagram of a circular economy (see below, figure 1) establishes a hierarchy of strategies to retain these aspects and avoid premature loss. The inner loops on the 'technical' side of the diagram are strategies which preserve more value and embodied energy such as reuse, repair, and remanufacture of products.[62] Recycling is the outermost of these loops. It represents an important aspect of a circular economy but should be used as part of a holistic approach to product lifetime extension and waste mitigation alongside the other strategies in the diagram.[63] Products should be maintained at a high level for as long as possible to make efficient use of the product's embodied energy, to avoid a loss of material value, and to retain valuable intellectual property.

Burden of responsibility

A waste mitigation strategy focused solely on recycling enables suppliers to avoid responsibility for their products and places a significant burden of responsibility on local authorities and consumers (this is despite the majority of the eventual impact being pre-decided at the design stage of a product). Similarly, a growing number of last-mile distributors who want to take responsible action on e-waste are also disadvantaged; restricted from doing much more than 'end of life management' or selecting the best quality/most durable product for their market. Consumers generally have little incentive to recycle nor are they knowledgeable about how and what to recycle. In target markets for off-grid solar products, the necessary support infrastructure for recycling is also either under-

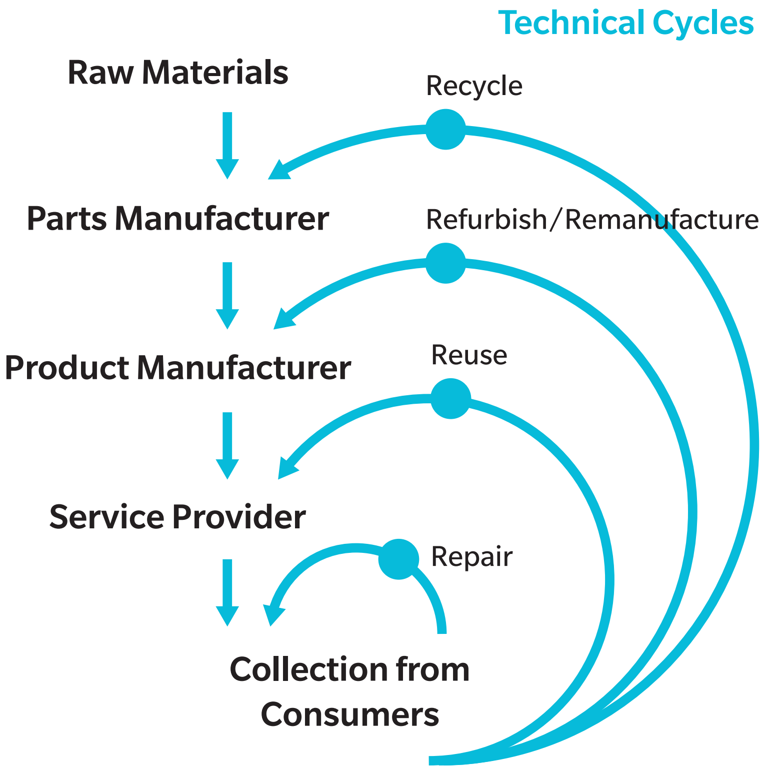
60. See: DFID/Sofies 2016 *Electronic waste (e-waste) impacts and mitigation options in the off-grid renewable energy sector.* https://tinyurl.com/yy92cyjs; See also, ongoing Global LEAP Solar E-Waste Challenge Rounds 1 and 2
61. Different plastics used in the enclosures must be separated to avoid contamination; batteries must be carefully extracted and stored to mitigate fire risk.
62. See: Ellen MacArthur Foundation. www.ellenmacarthurfoundation.org/explore/circular-design
63. Nancy M. P. Bocken, Ingrid de Pauw, Conny Bakker & Bram van der Grinten. 2016 *Product design and business model strategies for a circular economy, Journal of Industrial and Production Engineering*, 33:5, pp.308-320.

developed or non-existent. Suppliers are equally lacking incentives to assume responsibility where their end-of-life products represent only an economic drain. As a result, the potential benefits of recycling are reduced. In other sectors, extended producer responsibility legislation has been introduced to ensure that responsibility for recycling rests to an appropriate level with manufacturers. Off-grid solar companies have an opportunity to be proactive and head off the need for extended producer responsibility legislation.

Holistic waste management

There is an important place for recycling as part of a holistic waste management and mitigation strategy. Some waste analysts recommend that recycling efforts should target material flows which do not compete with existing repair and refurbishment practices, but rather focus on the "residual fractions and products that are finally disposed."[64] This approach would reduce the investment necessary to scale up the recycling of off-grid solar related e-waste.

Figure 1: Technical Cycles of a Circular Economy



64. DFID/Sofies 2016 *Electronic waste (e-waste) impacts and mitigation options in the off-grid renewable energy sector.* https://tinyurl.com/yy92cyjs, p14.

4. BARRIERS TO REPAIR

This chapter examines issues that may restrict a company's ability or willingness to design repairable products or support repair, as well as the challenges experienced by a user when seeking or attempting repair.

The barriers to a supplier when designing the product and business model are very different from the challenges to a user when trying to get any particular product repaired. This chapter examines each point in turn and provides a general overview (see Table 2).

Table 2: Barriers of Repair Overview

	PRODUCT USERS	MANUFACTURERS AND DISTRIBUTORS*
Economic Barriers	• Costs • Access to spare parts • Quality of repairs	• Revenue loss • Costs • Economies of scale • Access to spare parts • Safety and security concerns • Inadequate legislative support
Environmental Barriers	• Reduction in CO2 emissions • Reduction in e-waste volumes	• Product durability • Logistics
Societal Barriers	• Insufficient information	• Non-repairable design • Insufficient information • Definitions and metrics • Resistance to change

*Not all barriers are directly relevant to specialist distribution companies

ECONOMIC BARRIERS

Revenue loss

Some stakeholders operate business models which rely on repeat sales of the same new product. There is understandable concern that, by increasing the repairability (and thus extending the lifetime) of their products, they will experience a loss in revenue from those sales. This is certainly a significant issue in a saturated market. It is, however, estimated that the potential global off-grid solar market, despite strong sector growth, is between 840 million and 1 billion people.[65] Increasing product repairability also presents business models which have alternative means of encouraging and strengthening repeat business.

Costs

For users, the costs of undertaking repair can be significant, sometimes equivalent to the second or third largest cost factors for the entire system.[66] For companies, the associated financial costs of changing business and product strategies can be substantial and prove to be beyond the scope of viability for long and newly established companies alike. In addition, the costs of importing spare parts not otherwise available in off-grid markets - including import taxes/fees, as well as transportation and FOREX variations - can make repair prohibitive.

65. See: Lighting Global 2020 *The 2020 Global Off-grid Solar Market Trends Report*

66. Lemaire, X., 2011. *Off-grid electrification with solar home systems: the experience of a fee-for-service concession in South Africa. Energy for Sustainable Development,* 15(3), pp.277-283; Baurzhan, S. and Jenkins, G.P., 2016. *Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries?*. Renewable and Sustainable Energy Reviews, 60, pp.1405-1418.

Economies of scale

Building repairability into a product line or commercial business requires companies to achieve economies of scale to make repairs economically viable for themselves. This barrier is primarily applicable to newer, smaller companies. Meanwhile, there is little data on the potential market value for repaired products. The value of a repaired component or product will depend on the specific context, including the economic circumstances of potential customers and the availability of low-cost replacements. Supporting local repair can still be achieved however, regardless of scale and with myriad benefits, through the supply of repair information and spare parts.

Access to spare parts

Access to appropriate and high-quality spare parts is a crucial barrier to repairability for both users and equipment manufacturers.[67] Products do not use identical parts and updated models frequently introduce new components. Meanwhile, irregular and dispersed demand for spare parts and components can make the supply chain logistics challenging.

However, increasing the availability of spare parts and critical components for off-grid solar products is an essential part of ensuring their repairability, supporting job opportunities and livelihoods in repair markets, and minimising the loss of energy and materials in electronic waste flows.

Without access to quality assured components, for example, third-party repair technicians will often use whatever is available, including salvaged parts from other products. Engaging directly with third party repairers and working to more effectively distribute essential spare parts in places where they are most needed can help to enhance the quality, and likely success, of repair attempts.

Many manufacturers and distributors face challenges importing spare parts and transporting them in-country, including barriers on the import of spare parts, which may require changes in policy incentives. Increasing investments in local manufacture and assembly can also help to overcome these challenges, whilst significantly increasing the availability and access of critical parts and components in off-grid markets.

Commitments to interoperability (see Chapter 5) – whether across a company's product range or across the sector – can also help to address these issues by increasing the backwards compatibility of parts and components, and keeping materials in a high-value loop for as long as possible.

Safety and security concerns

For many manufacturers, the prospect of opening up the repair of the core system to third parties carries risks for the consumer and the repairer. Off-grid systems can involve large amounts of stored energy so there are safety and product liability considerations, particularly around the use of batteries and appliances which are not from the original supplier. However, without further detailed study of the capacity of third-party repair providers, whether in the formal or informal market, it remains unclear to what extent these perceived risks are borne out.

Many manufacturers have additional security concerns related to their intellectual property. Some are reluctant to design systems for repair and disassembly because of fears that this will makes it easier for people copy internal components or rewire internal circuitry in order to bypass smart payment mechanisms. The increasing popularity of PAYGO systems make such concerns particularly important.

However, this is not a 'zero sum game'. Copyright infringements take place regardless of whether products are designed to be taken apart when competitors reverse engineer existing products and deliberately replicate designs and dressing.[68] Similarly, people will continue to attempt to circumvent proprietary closures or bypass payment systems regardless of whether they have been designed to be easily repaired by

67. European Parliament 2019 *Consumers and Repair of Products.* Briefing Paper. https://tinyurl.com/yy34894b. p.3.
68. See, for example, the case of d.light design Inc vs Boxin Solar Co. Ltd: https://tinyurl.com/y2zlbdsb

third parties.[69] Similar concerns are shared by all manufacturers of electronic goods and pay-as-you-go services, but these are not arguments against repair, per se. Manufacturers of PAYGO devices (see Case Study 2) have demonstrated that it is possible to respond to security concerns with software rather than hardware; designing physical products that enable repair whilst protecting remote payment systems.

Inadequate legislative support

In certain markets, it is costly to import spare parts. For example, the Kenyan Bureau of Standards only allows spare parts to be imported for products that can prove successful completion of "sampling, testing and analysis in accredited laboratories."[70] Off-grid solar companies can use a current or recently expired (i.e. valid within the last 12 months) Type Approval Certificate and/or an associated Test Report from the VeraSol quality assurance program for this purpose. But this means spare parts cannot be imported for older off-grid solar products or those with a lapse in certification greater than 12 months. The VeraSol certification process can cost suppliers thousands of US dollars per product. As such, off-grid solar companies are economically disincentivised from seeking certification for older products just so they can import spare parts to facilitate repairs. If acceptance of legacy VeraSol certification were to be further extended by Kenyan Bureau of Standards - only in relation to products either nearing the end of production, or out of production altogether- then spare parts may be easier to import and thus be more accessible for manufacturers, end-users and third party repair service providers.

Policy makers can further support repairability by introducing economic incentives such as reducing VAT on repair services and creating national accreditation registers for repairers independent of those for manufacturers.[71]

ENVIRONMENTAL BARRIERS

Product durability

Repairability and durability are sometimes seen as separate and incompatible.

A frequent concern expressed by off-grid solar companies is that efforts to increase product repairability will reduce a product's ability to survive sustained use in often harsh environments. Products that are easier to open, for example, often loose the ingress protection required to keep out dust and rain.

Durability is an important tool for manufacturers to protect their intellectual property and business goals – by limiting the capacity of product users to tamper with internal components and payment systems. Many companies are concerned that increasing the repairability of products will inhibit their ability to provide an effective, cost-efficient warranty service that protects business goals.

But durability is not solely derived from a product's sturdiness or ability to withstand damage- intentional or otherwise. Design for repair and design for durability are not mutually exclusive strategies for improving or extending product lifetimes.[72][73] "Design for durability" and "design for ease of maintenance and repair" can be employed together within a circular design strategy that aims to retain value whilst allowing for materials to be recovered and recycled.[74]

69. Houston, L. and Jackson, S.J., 2016, June. *Caring for the" next billion" mobile handsets: opening proprietary closures through the work of repair.* In Proceedings of the Eighth International Conference on Information and Communication Technologies and Development (pp. 1-11). See also: https://tinyurl.com/yy7n9r7u
70. See: www.intertek.com/government/kebs/
71. European Environmental Bureau 2019 *Cool Products Don't Cost the Earth.* https://eeb.org/library/coolproducts-briefing/
72. Ertz, M., Leblanc-Proulx, S., Sarigöllü, E. and Morin, V., 2019. *Made to break? A taxonomy of business models on product lifetime extension.* Journal of Cleaner Production, 234, pp.867-880.
73. This overlap is further reinforced in European standard EN 45552:2020 (*General method for the assessment of the durability of energy-related products*), which includes the ability to maintain and repair within their definition of product durability.
74. Bakker et al., 2019 *Products That Last*. p97.

Logistics
Centralised models of repair involve specific logistical challenges. These hinge on the difficulties of collecting broken products for repair, transporting spare parts to the point of repair, and delivering fixed or replacement products back to their end user. These logistical challenges are far greater to overcome in particular geographic contexts and rural markets, further from transportation hubs.

SOCIAL BARRIERS

Insufficient access to repair information
The Ellen MacArthur Foundation states that "access to repair information is of crucial importance for enabling repair".[75] Few, if any, pico solar or solar home systems are sold with instructions on how to perform basic repairs, nor are instructions readily available online. This greatly extends the time necessary to attempt a repair whilst also reducing the efficacy and reliability of the result.

Current initiatives seek to address this issue. The first round of the Global LEAP Solar E-Waste Challenge supports multiple projects currently exploring how best to convey effective repair information, learn more about contexts of repair, and incentivise the return of broken and faulty products. The lack of information is also a challenge for companies. Where repairs are conducted entirely by third parties, the ability of companies to collect information on failure rates and common faults, and to find value in this process, is limited.

Non-repairable design
Many businesses need to find cost efficiencies in high volume manufacturing, in order to produce ultra-affordable off-grid solar lighting products that meet minimum quality assurance standards has led to non-repairable product designs. Difficulties in accessing product enclosures make it more difficult to remove broken or faulty components.

Definitions and metrics
Definitions and measures of product health continue to vary. For example, lead acid batteries that might be defined as "broken" and ready for recycling according to specific battery health diagnostic tools may still be viewed as functionally operational and adequate for continued, everyday use according to other metrics. In some cases, the difference is a question of liability.

Resistance to change
Many business leaders in the sector are working hard to establish sustainable, profitable and impactful businesses in challenging circumstances. For some people, however, the prospect that off-grid solar companies could deliver deeper social and environmental gains by pushing the limits of sustainability in product design and business will be a source of personal and professional motivation. For these people, the challenges of pivoting existing business models to more sustainable and circular alternatives will be something to embrace.

In many cases, however, companies may be locked into product designs and supply chains that limit their capacity to introduce the material, operational or logistical changes required to enhance repairability. New costs will have to be closely interrogated in order to assess whether it delivers value for money and will help keep the business competitive. If business leaders are resistant to accelerate action on repair, it may be that the business or impact case has not yet been presented in a compelling way, or that the external pressures that might precipitate such a shift are not yet present.

Lorentz designs, manufactures, and distributes solar pumping systems, solar-powered water dispensers and associated products to over 150 countries. The company is focussed on designing for off-grid scenarios: all of their design and manufacturing occurs in-house allowing them to engineer products from the ground up with the efficiency and reliability their product applications require.

75. Ellen MacArthur Foundation 2016 *Empowering Repair*, p9. https://tinyurl.com/yybhewzb

CASE STUDY 2: LORENTZ

Lorentz understands that having a reputation for well-designed products and providing customer support over a long lifetime is beneficial to its business. Its B2B customers and end-users value that products are repairable, that all parts are readily available and that spare parts are not sold at a premium.

The company's products, much like solar lighting products, are typically installed in hard to reach places where people are reliant on their continued functioning. Product repairability enables Lorentz to reduce downtime in the event of a failure, supporting the companies which sell their products and the communities that depend on them.

Preventative repair
Lorentz's design philosophy incorporates a preventative approach to repair emphasising the importance of utilising materials and designs that are least likely to fail and keeping repair to a minimum.

Ease of replacement
Products are split into easily exchangeable components which, for electronics, can mean adding cost with multiple PCBs and ribbon cables.

Components which may be damaged by external influences (such as voltage spikes or lightning strikes) are grouped onto the same replaceable boards. These are then placed where they are easy to exchange.

Sub-components which are most likely to fail are also easy to exchange.

Interoperability
Some sub-components are common across multiple products. Lorentz has designed PCBs which are used across products ranging in power from 150W to 100kW. This reduces the number of spare parts that service partners need to hold.

Component identification
Components are clearly marked to help with identification during a repair. The company further simplifies PCB identification by using different colours of solder mask for different boards.

Reduction in required tools
Where possible no tools are required to conduct a successful repair, but where necessary commonly available tools are prioritised. To aid in this effort, Lorentz's products strive to use a single type of fastener per unit.

The company offers a diagnostic smartphone app which offers meaningful error reporting and allows users to view real-time data related to their product. This app simplifies repair by enabling a technician to quickly understand a fault before they have opened the product and without the need to use more specialised tools such as multimeters.

Image: Lorentz's smartTAP water dispenser with front cover removed

In this chapter, we outline business model archetypes that are complementary to repair strategies. The selection of these models is based on a typology of circular business models developed by the Organisation for Economic Cooperation and Development.[76]

Some off-grid solar product companies follow one or more variants of the models described below and, where applicable, we provide relevant examples alongside the business model description. Further discussion is merited to find the best strategies to integrate such models in off-grid energy products businesses to make off-grid products more amenable for repair.

PRODUCT SERVICE SYSTEM MODELS

Product Service System models combine a physical product with a service component and have many variants. Some put more emphasis on the product and some on the service itself. The stress on provision of service provides an incentive for the company offering the product service system to keep the system fully functioning at all times. The company is also in more frequent touch with the customer when compared with non-product service system models. This helps ease reverse logistics issues typically associated with keeping repair processes affordable.

There are four key variants of the Product Service System model:

- Warranties or after sales service agreement
- Renting or lease-based
- Product as a service
- Pay-As-You-Go

Products with warranties or after-sales service agreements are fairly ubiquitous in the organised formal segment of this market.

Renting or lease-based models, and product-as-a-service models both contribute to an intensification in product use (because several users/households access the product during its technical life).

Renting or lease-based models and product-as-a-service models lead to obvious environmental benefits by reducing the emphasis on “one product per user/household” and reducing the resource footprint required to increase energy access. Furthermore, since companies retain the ownership of the product or system, these models promise timelier repair. They allow better visibility on the most common types of repair issues that may be encountered and undertake the most efficient stocking of spare parts.

A PAYGO model may be regarded as another variant of a Product as a Service model. The key difference is that ownership is eventually transferred to the user, after completion of payments.

While a product as a service model is especially common in the cooling sector (examples include KoolBoks and ColdHubs, two off-grid cold room companies operating in Nigeria) the model is also being adopted in several other applications such as batteries (examples include Betteries and Aceleron), mobility (an example is Mobility for Africa) and even irrigation pumps (an example is Claro Energy).

RESOURCE RECOVERY MODELS

Resource recovery models focus on recycling. They have important synergies with enhancing product repair. This model alludes to the effective recycling of off-grid solar products at the end of life with the goal of production of secondary raw materials from waste streams.

76. OECD 2019 *Business Models for the Circular Economy: Opportunities and Challenges for Policy*. https://tinyurl.com/y4tffpd3

These models involve:

- effective collection of waste streams
- effective sorting of waste streams
- secondary production with raw materials from sorted waste streams

Each of these activities can be undertaken by different market actors.

To achieve true demand for secondary raw materials, effective valorisation of waste stream materials and adequate infrastructure for recycling is key.

For example, most of the current global recycling infrastructure for batteries targets the recovery of cobalt, while the off-grid solar sector primarily uses lithium-phosphate and lithium manganese oxide batteries, which do not contain cobalt.[77] Given the enormous quantities of spent Li-ion batteries in off-grid solar lighting products, and the growing demand for Lithium from the electrical vehicle sector, there is an opportunity for commercialising new battery-recycling technology.[78] Developing not only the technology but also the use case and business model is key to success. A mature recycling infrastructure for off-grid solar products will also involve setting up appropriate reverse logistics supply chains which can be potentially leveraged for product repair. Effective recycling can also lead to improved spare part availability in the form of reclaimed components that have been verified for adequate technical performance. These components can potentially be used for both off-grid solar product repair and refurbishment processes.

CIRCULAR SUPPLY MODELS

Circular supply models entail the use of bio-based, renewable, or recovered materials as far as economically feasible in production. To the extent the materials used in production are able to decompose naturally and return to the environment, this model also helps to design away waste.

Some off-grid product manufacturers are leading innovations in this field.

- Ecolife, a social enterprise based in Uganda uses locally available insulation materials such as agricultural waste for constructing cold rooms.
- Servedonsalt or SOS is a company at a prototype stage at the time this working paper was being drafted, and is experimenting with the use of a heat battery made of a special salt, which if successful could help manage battery e-waste while bringing in co-benefits of distributed manufacturing.
- Mango Solar a solar home system developer that plans to explore the use of bio-based plastics as a production material in the mid-term (see Case Study 1).

Use of alternative, or low carbon materials can be beneficial from a repair perspective, especially if these materials are locally sourced thus helping with spare part availability and/or if they reduce the complexity of repair as in the case of Servedonsalt's salt battery. They also help bring in co-benefits of diversification of raw materials sourcing locations and reduce the dependency on supplies from a single country. Depending on the cost of new materials that substitute old ones, there can be additional affordability benefits.

77. SOFIES, 2020. *E-waste Management Recommendations for BGFA Programme*. https://tinyurl.com/y36gdzmq
78. See, for example, Acceleron's second life battery project under the Global LEAP challenge: https://www.acceleronenergy.com; Harper, G., Sommerville, R., Kendrick, E., Driscoll, L., Slater, P., Stolkin, R., Walton, A., Christensen, P., Heidrich, O., Lambert, S. and Abbott, A., 2019. *Recycling lithium-ion batteries from electric vehicles*. Nature, 575(7781), pp.75-86.

DECENTRALISED REPAIRS

Returning products to the original manufacturer for repair require investment in reverse logistics, which poses a key cost and affordability constraint in the context of off- and weak-grid rural economies. A decentralized approach to repair can help. Based on the degree of decentralization in repair process approach, three variants of this model emerge.

Training product distributors for repair
Making spare parts and appropriate repair tools available at each distributor's level is an important approach, which least conflicts with the manufacturers need to protect product IP while outsourcing repair.

Leveraging third party repair technicians in the informal economy
Third party repair technicians are ubiquitous in many off-grid markets across sub-Saharan Africa and South Asia. Rather than see these technicians as impediments to repair, they are an important part of the solution. They are often generalists in repair rather than specialists in one type of product or brand repair. This would enable companies to leverage an existing ecosystem of collection and repair, already accessible and widely used by end users.

Empowering end-users
A third model includes making provisions for providing spare parts and repair guides publicly to the customers to repair the products themselves or by a third party.[79]

LOCAL ASSEMBLY OR LOCAL MANUFACTURING

Locally assembling solar products, using some degree of locally manufactured components can have substantial impacts on improving availability of spare parts and appropriate repair tools. In addition, there are important co-benefits of local skilling and job creation, and improved business resilience by diversifying and reducing dependence on global supply chains. Local assembly has major environmental, social and economic benefits, making this a critical pathway to reducing the full lifecycle costs of product use (see, for example, Case Study 1).

INTEROPERABILITY

Interoperability describes the use of standardised or interchangeable components or accessories across product lines and models. Increasing interoperability creates new opportunities to extend the life of a product by allowing individual components, rather than entire systems, to be replaced once options for repair have been exhausted.

GOGLA and its members are currently working to enhance interoperability by standardising connectors, communications protocols and devices controls across the sector. Some off-grid solar companies already combine elements of interoperability and repairability under the umbrella term "refurbishment". This might range from minor cosmetic adjustments to deep circuitry repairs.

Repair is likely to become easier as action on interoperability makes some spare parts (like connectors) more common across product brands and types, and increased volumes in the market lower their prices. Interoperability allows parts and components to be salvaged from different, older or faulty products, when they can no longer be repaired, and used to restore function in another product.

79. Global Off-grid Lighting Association 2019. *E-Waste Toolkit*

SMART PRODUCTS

The use of Internet of Things (IoT) protocols to create 'smart' products can substantially enhance repairability. Data loggers within these products offer a remote troubleshooting ability. Device and component level performance data are collected during product use and analysed to identify faults, often predicting a fault prior to any disruption to the energy service for the user. This leads to improved instances of preventative maintenance. Identifying key types of repair instances remotely also leads to impacts such as product lifetime extension for users and can feed into future design improvements for manufacturers. If parts with technical issues can be identified remotely, the cost of last-mile servicing can be reduced; technicians can be sent with appropriate tools and spare parts for repair reducing the number of required visits, time and cost of repair. In the case of productive use appliances, avoided disruption in product use will limit the impact to the income-generating potential of the product. (See 'Case Study 3: Innovex' below.)

Internet of Things (IoT) protocols are currently most viable in solar home systems and larger appliances, due to the cost implications and the reliance on external GSM infrastructures. The inclusion of IoT technology within a product, or product system, naturally increases its complexity, so it is important to ensure that these additions are, themselves, easy to repair.

Founded in 2016, Innovex is a Ugandan company which aims to spur Africa's socioeconomic transformation through the development of novel technologies. Its competences include embedded systems, connected devices, web and software development, and wireless communication technologies. Innovex entered the market with a home-grown IoT solution. This solution, 'Remot', offers after-sales service support; remotely monitoring and controlling solar PV systems and equipment, and supporting preventative maintenance and repair activities. To-date, 'Remot' has been used in over 5 countries in Africa by solar companies and solar energy researchers.

Preventative maintenance
Innovex's 'Remot' system consists of a locally manufactured smart meter and an in-house cloud-based web system. The smart meter tracks a number of parameters from the solar system including solar production, battery health, and load consumption. This data is then sent wirelessly to the cloud-based web platform. Using data analytics, the cloud-based platform provides useful performance information and key system alerts such as battery state of charge, system overload, and extreme ambient and battery temperatures alerts. With these data-driven features, solar companies can remotely diagnose any faults and quickly respond to prevent product breakdowns. Technicians are able to establish points of failure prior to site visits, allowing them to respond with the appropriate components and knowledge necessary to conduct repairs.

Local manufacturing
Working with the Carbon Trust under the Transforming Energy Access programme, Innovex has established a local surface-mount technology and plastic manufacturing facility for its products. This establishment seeks to ensure local value addition by providing better job opportunities for local product developers in the solar energy space while increasing accessibility to product spare parts. Innovex has also stimulated the local product development industry by sourcing product components and making them available at affordable prices on the local market.

Interoperability
Similar components are used across all Innovex product lines making it cheap and easy to source and replace broken components.

Image: Innovex's 'Remot' IoT hardware with front cover removed

In February 2020, the European Standards Body published a new, internationally recognised methodology framework for objectively assessing the repairability of household electrical appliances.

EN 45554:2020 - 'General methods for the assessment of the ability to repair, reuse and upgrade energy-related products' - was prepared by 105 registered experts, with stakeholder representation from suppliers and manufacturers, European member states, academics, and NGOs.

The standard was finalised through a consensus-based process led by the European Committee for Electrotechnical Standardisation, and its working group on 'Energy Related Products – Material Efficiency Aspects for EcoDesign'.

The new standard defines the parameters and methods required to assess:

- the ability to repair and reuse products;
- the ability to upgrade products, excluding remanufacturing;
- the ability to access or remove certain components, consumables or assemblies from products to facilitate repair, reuse or upgrade

The framework has been developed to allow for product-specific details to be developed.

The standard provides an internationally agreed upon and formalised way to define what is meant by a 'repairable' product. There are 11 assessment parameters (see Table 3).[80]

Additional guidance is given in the EN standard for each parameter. The framework is designed for specific use by different stakeholders. EN 45554 is not, however, a stand-alone solution for all appliances: it provides an assessment framework and further details will be needed that interpret the assessment parameters and methodologies for each product type. These could be developed and published in a separate standard or other industry reference document. Market benchmark levels of reparability (average, best practice) can then be established for products, as iFixit[81] has done for consumer electronics products. Such scoring can then underpin policy interventions such as promotion, endorsement, procurement specifications and financial incentive schemes.

In summary, the new European Standard provides a methodological framework:

For suppliers to:

- Quantify how repairable their products are
- Design products and business models that clearly enable repairs
- Compete fairly on repairability

For policy makers to:

- Focus on ways to explicitly encourage repairs
- Encourage repairability through policy
- Establish QA schemes that assess and report on reparability quantified in an objectively comparable way
- Develop a consumer facing label (e.g., the more stars, the more repairable it is)
- Ensure that products that are mass-procured by the hundreds of thousand address reparability to a defined extent.

For buyers to:

- Use published scores to judge how repairable products are
- Choose between products based on their repairability scoring, alongside other priorities.

80. European Committee for Electrotechnical Standardisation 2019 *General methods for the assessment of the ability to repair, reuse and upgrade energy-related products* EN 45554:2020 (E), Annex A
81. iFixit publishes reparability scores for popular consumer electronics devices, such as tablets at https://www.ifixit.com/tablet-repairability?sort=score.

Table 3: List of Assessment Parameters in EN 45554:2020

ASSESSMENT PARAMETER	METRIC FOR ASSESSMENT
Number of steps to remove key parts	Time taken for disassembly and an index based on complexity of the process.
Fasteners used for key parts	Scoring based on number and type of fasteners for key parts and whether re-usable, removable or neither of these.
Tools necessary for repair	Suggested grades: No tools needed; basic tools (e.g. using a specified basic set of 18 tools); tools specific to the product group; commercially available tools; proprietary tool set; not feasible with existing tools.
Type of workshop needed to do repair	Degree of specialisation of the workshop: no special requirement, professional workshop or original manufacturer environment.
Technical skill of person	5 levels: layman, generalist, expert, authorized expert, manufacturer.
Availability of diagnostic information	Aid given to help find the problem, assessed based on the ease of interface use required for fault-finding as supplied or presented by the product itself.
Availability of spare parts	Assessment grading for standard versus proprietary parts; their availability to public or specialists; period for which parts are made available after sale.
Availability of repair instructions	How comprehensive the information is and to whom it is made available (public or specialists by type): schematics, reference values, troubleshooting, parts lists etc.
Ease of return of used or defective product	Return process (such as mail-back) exists, or it does not.
Personal data deletion	To enable transfer ownership without transfer of personal data (for ICT equipment). 'Built-in', 'on request' or 'not available'.
Product Reset	Extent that restoration of factory settings is enabled for safe reuse (for ICT equipment). Integrated reset (by user), external reset (needs additional software or aid), service reset (by supplier) or no reset possible.

Many in the global off-grid solar sector are motivated by the prospect of building a more sustainable future.

As the world seeks to build back better from the COVID-19 pandemic, this is an opportunity for the sector to show new leadership. Thinking more holistically across the life cycle of off-grid products would allow the sector to connect the UN's goals for universal energy access to its goals for sustainable consumption and production.

To this end, we have identified seven short- and long-term pathways to enhancing repairability in the sector focused on standards, incentives, business models, product design, reporting and awareness raising, and research.

1. STANDARDS AND CERTIFICATION

Few industry stakeholders would support the introduction of mandatory standards on repair by governments or regulators at this stage in the sector's growth. But key stakeholders in the sector do recognise that sector wide repairability standards can add value for off-grid solar businesses and accept that standards are a vital tool for enhancing pathways to repairability.

Develop assessment metrics for off-grid products
An objective assessment method for rating the repairability of every off-grid product can now be developed using the European Standards framework (EN 45554). This could be delivered by a working group of off-grid specialists convened by an industry association or similar. It could be published first as an informal standard, with adoption as a formal international standard in due course with sufficient backing.

Adapt EN 45554 for the off-grid solar sector
A future repairability standard based on the European Standards framework (EN 45554) are a very good option for the off-grid sector. GOGLA's Circularity Working Group has recently held discussions on the development of a voluntary repairability standard. A new standard would help manufacturers think through repairability and circularity in terms of product design, policy, strategy and operations; it would also provide companies with a new metric for reporting on sustainability; it would act as a guide for suppliers; and it would allow investors and sector support programs to benchmark and promote good practice.

Add repair to quality certification
Adding repair to existing VeraSol quality certification schemes or developing a specific quality metric is key to making progress in this area. Future action should examine the need and scope for extending existing quality assurance frameworks.

Support legacy certification
In some national markets (e.g. Kenya) spare parts and components can only be imported for off-grid products with supporting documentation obtained via the VeraSol quality assurance program. Extending the support of legacy certification for products either nearing the end of production, or out of production altogether may make spare parts easier to import and thus more accessible for repairers.

2. POLICY AND FISCAL INCENTIVES

There are different strategies to enhance repairability across the sector through policy action and fiscal incentives.

Update procurement policies
By adding repairability into the procurement policies and procedures, institutional customers like governments, charities, and international agencies can extend their commitments to social responsibility, and ethical economic and environmental impacts. Adding repairability to tendering and lotting strategies can assist companies in bringing about a change in business practices, mitigate risks from the disruption of future supply chains, and help to foster innovation across the off-grid sector. Updated procurement policies could be based on existing assessment metrics and standards for energy related products (like EN4554) or future, sector specific metrics (see above).

In some contexts, like humanitarian emergencies, procurement is extremely price-sensitive, time-sensitive and often non-recurrent. In these contexts, off-grid solar products that can be used and repaired in-situ may promise increased value for money, by meeting both short term goals around the provision of basic energy access as well as longer-term goals around livelihoods and economic development.[82]

Use investment to drive change
Investors and development agencies will be important drivers of change in the off-grid solar sector. Investors can encourage and promote repairability by linking this to new equity or debt, and by acknowledging the importance of repair for brand image and risk mitigation. Development agencies can drive change in the sector too, by adding repair targets or metrics to energy access and solar market development programmes, funding schemes, tendering requirements and research and development calls. Increased awareness amongst investment and donor communities of the economic, social, and environmental benefits of repair can nudge the sector as a whole.

Incentivise repair
With new commitments from European governments, there is new international attention on the policies and fiscal incentives that can support repair economies. These are also important across many off-grid markets, linking repairability to energy access goals, as well as livelihoods, jobs and employment. To support the growth of the repair economy, policy makers can keep import taxes and duties on spare parts low; reduce or eliminate VAT on repair services; and ease restrictions on the import of spare parts for off-grid energy technologies.

82. New research in this area is currently being undertaken by the University of Edinburgh, in collaboration with the UNHCR's Innovation Service and Chatham House: See: https://blogs.ed.ac.uk/repair/

3. LOCAL MANUFACTURING AND REPAIR SERVICES

The alternative to designing new products that can be repaired in the future is to repair what is already there, by building businesses that extend the life of products, supporting local manufacturing and repair services.

Emerging archetypes demonstrate how repair strategies can be incorporated into or made complementary to existing business models.

Local manufacturing
In-country manufacture and assembly would localise technical expertise and component warehousing, crucial elements in sustaining efficient after-sales support and fault correction. Investments in local manufacturing will also, in the longer term, serve as a guarantee that spare parts and repair expertise are locally available. The African Union sees the COVID-19 pandemic as an opportunity to recentre manufacturing and supply chains, reducing dependency on Chinese manufacturing.[83] Many African countries are looking to reposition their economies in the aftermath of COVID-19 by diversifying their centres of production and by equipping young people with the skills needed to attract multinational enterprises.

In-house repair
Some existing products may best be repaired in-house. If so, companies may consider extend their reverse logistics operations to ensure that all customers are able to avail of these services. Manufacturers and distributors may also consider how to provide customers with information and advice about post-warranty repair, perhaps with financial support from market development programmes.

Third-party repair
Build new partnerships with the informal sector. Invest in training and capacity building to develop networks of registered, accredited service providers for off-grid solar products.

Spare parts suppliers
The supply of key components and spare parts across multiple product lines may prove to be a viable business proposition.

4. BUSINESS AND IMPACT METRICS

Add repair to impact metrics
Building repair and repairability into existing social, economic and environmental impact metrics for the off-grid solar industry - like those supported by GOGLA - is a key lever for changing design practices and business models.[84] Repair delivers multiple benefits (see Chapter 3). Making these benefits a visible part of impact reporting and evaluation will help to reward companies that are developing repairable products and business, incentivise their competitors, and provide investors with appropriate measures of success.

Recognise repair as reputational
Action on repairability creates a win-win for equipment manufacturers, donors, investors and consumers by further establishing the sustainability credentials of solar energy systems and solar powered products in a circular economy. Focus on improving/encouraging solar companies to improve the repairability of products and extend useful life for their own operations – and then build out from there.

83. African Union 2020 *Impact of COVID-19 on the African Economy*. https://au.int/sites/default/files/documents/38326-doc-covid-19_impact_on_african_economy.pdf
84. For further detail on GOGLA's standardised impact metrics: https://www.gogla.org/impact/gogla-impact-metrics

Partner with third-party repair providers and field technicians
Third-party repair technicians are already an essential part of off-grid solar economies in sub-Saharan Africa and South Asia. They keep products operational beyond their warranty period and reduce electronic waste. Even if they do not have formal qualifications or training they can be treated as skilled and knowledgeable partners. By measuring and accounting for the impact of third-party repair on informal livelihoods, solar companies can significantly expand their claims to social and economic impact.

5. PRODUCT DESIGN

There is no one-size-fits-all approach to enhancing repairability in product design. Solar products, and the companies that manufacture them, come in all shapes and sizes. Different approaches will make sense for different products and different companies.

Follow the EN 45554 Standard
The new standard provides an internationally agreed upon and formalised way to define what a 'repairable' product looks like. Using this as a guide in the design of future off-grid solar products is a simple, straightforward and positive commitment to best practice.

Design holistically
Design strategies must be applied holistically to maximise sustainability. With easier access to quality spare parts, repair information and diagnostic tools, repairs are not only easier, but also safer.

Design for repair and interoperability
Combining strategies would make it easier for people to move up the energy access ladder and lead to longer-lasting products as people pay for products to be fixed.

Balance durability with repairability
A sole focus on extending product lifetimes and functionality through increased product sturdiness and ingress protection may, ultimately, result in a less repairable product.[85] Different strategies can be combined: design for durability can increase the time before a limiting event is reached; design for repairability can extend component and product lifetimes beyond those limiting events. Other strategies - such as design for disassembly, design for remanufacturing, and design for recyclability – will follow.

Prioritise access to common failure points
Most end-users and repair service providers do not want or need to fully disassemble products; they want to restore functionality. Designing products in ways that ensure that common failure points – like switches and batteries – are easily accessible and replaceable by someone with access to appropriate spare parts and instructions is the most basic first step.

85. Such a product may reach the end of its functional life the instant one key component fails - irrespective of the condition the rest of the components are in. At the same time, a product which is too easily taken apart may be particularly susceptible to damage.

6. FURTHER RESEARCH

Further research is needed to better document and evidence the social, economic and environmental barriers and benefits to repair.

Expand evidence of impact and benefits
There is scope for further, sector specific research on the impact of repair on product users. Social and economic studies of the repair economy in off-grid markets should balance cost-benefit analyses of repair for companies with cost-benefit analyses of repair for consumers. This will likely require new methods for measuring and quantifying the social, environmental and economic impacts of repair in off-grid markets, and the benefits of repairability for off-grid solar businesses. Future research in this area will likely include assessments of the true economic implications of repair for consumers and companies; the costs to companies of implementing different levels of repairability; and the impacts of increased repairability on the affordability of off-grid products.

Expand the knowledge base around good practices, business models and partnerships
What lessons can be learned from good practices, business models and partnerships in the sector? Expanding the knowledge base will help companies in the off-grid solar sector to pilot new initiatives and adopt their current strategies around repair, and to establish future strategies.

Undertake product-specific life cycle analyses
Product-specific life cycle analyses, like those undertaken by Total, can help emphasise the environmental relevance of repair and maintenance alongside broader strategies refurbishment, remanufacturing and recycling (see above, 'The Downsides to a Recycling Only Strategy'). These can help to evaluate what the environmental benefits are, in terms of Global Warming Potential, if the lifetime of solar products is increased by one, three, and five years through repair.[86]

86. Heiskanen, E. 1999. *Every product casts a shadow: but can we see it, and can we act on it?*. Environmental Science & Policy, 2(1), 61-74.

SELECTED BIBLIOGRAPHY

This bibliography contains a selected list of further reading, including links to other methodologies for reparability assessment and related material.

Bakker, C., den Hollander, M., Van Hinte, E. and Zijlstra, Y., *Products that Last 2.0: Product Design for Circular Business Models*, 2019, BIS Publishers.

Bocken, Nancy, M. P. Ingrid de Pauw, Conny Bakker & Bram van der Grinten "*Product design and business model strategies for a circular economy*", Journal of Industrial and Production Engineering, 2016, 33:5, 308-320

British Standards Institution. *Design for manufacture and assembly*, 2016, BSI 8887-211:2012

Chapman, J. (Ed). *Routledge Handbook of Sustainable Product Design*, 2017, London: Routledge

Cross, J. and Murray, D. "*The afterlives of solar power: Waste and repair off the grid in Kenya*." Energy research & social science, 2018, 44, pp.100-109;

Cross, J., Douglas, M., Grafham, O., Lahn, G., Martin, C., Ray, C. and Verhoeven, A. *Energy and Displacement in Eight Objects: Insights from Sub-Saharan Africa*. 2019, London: Chatham House. www.chathamhouse.org/2019/11/energy-and-displacement-eight-objects

Den Hollander, M.C., Bakker, C.A., Hultink, E.J. "Product design in a circular economy: development of a typology of key concepts and terms." *Journal of Industrial Ecology*, 2017, 21(3), 517e525.

DFID/SOFIES *Electronic waste (e-waste) impacts and mitigation options in the off-grid renewable energy sector*, 2017, https://tinyurl.com/yy92cyjs

Efficiency for Access *Sustainable E-Waste Management Practices for the Off-grid Sector*: 2019, Workshop Report. https://storage.googleapis.com/e4a-website-assets/SOGE-Workshop-EforA-Report.pdf

Ellen MacArthur Foundation Growth Within: A Circular Economy Vision for a Competitive Europe, 2015, https://tinyurl.com/y5daudmb

Ellen MacArthur Foundation. *Empowering Repair*, 2016, https://tinyurl.com/y2xp5gj5

Ertz, M., Leblanc-Proulx, S., Sarigöllü, E. and Morin, V. "*Made to break? A taxonomy of business models on product lifetime extension.*" Journal of Cleaner Production, 2019, 234, pp.867-880.

European Commission *Closing the Loop : An EU Action Plan for the Circular Economy*, 2015, https://tinyurl.com/y6f58cus

European Committee for Electrotechnical Standardisation *General methods for the assessment of the ability to repair, reuse and upgrade energy-related products* EN 45554:2020 (E), 2019

European Environmental Bureau. *Cool Products Don't Cost the Earth*, 2019, https://eeb.org/library/coolproducts-briefing/

European Parliament. *Circular Economy: definition, importance and benefits,* 2015 https://tinyurl.com/EUparl2015
European Parliament *Consumers and Repair of Products,* 2019, https://tinyurl.com/yy34894b

European Union *The Route to a Circular Economy*, 2018 *https://tinyurl.com/yy6d9vyb*

Global Off-grid Lighting Association. *E-Waste Toolkit,* 2019 www.gogla.org/e-waste

Lighting Global. *Eco Design Notes 7*, 2015 *https://tinyurl.com/yyh53mpv*

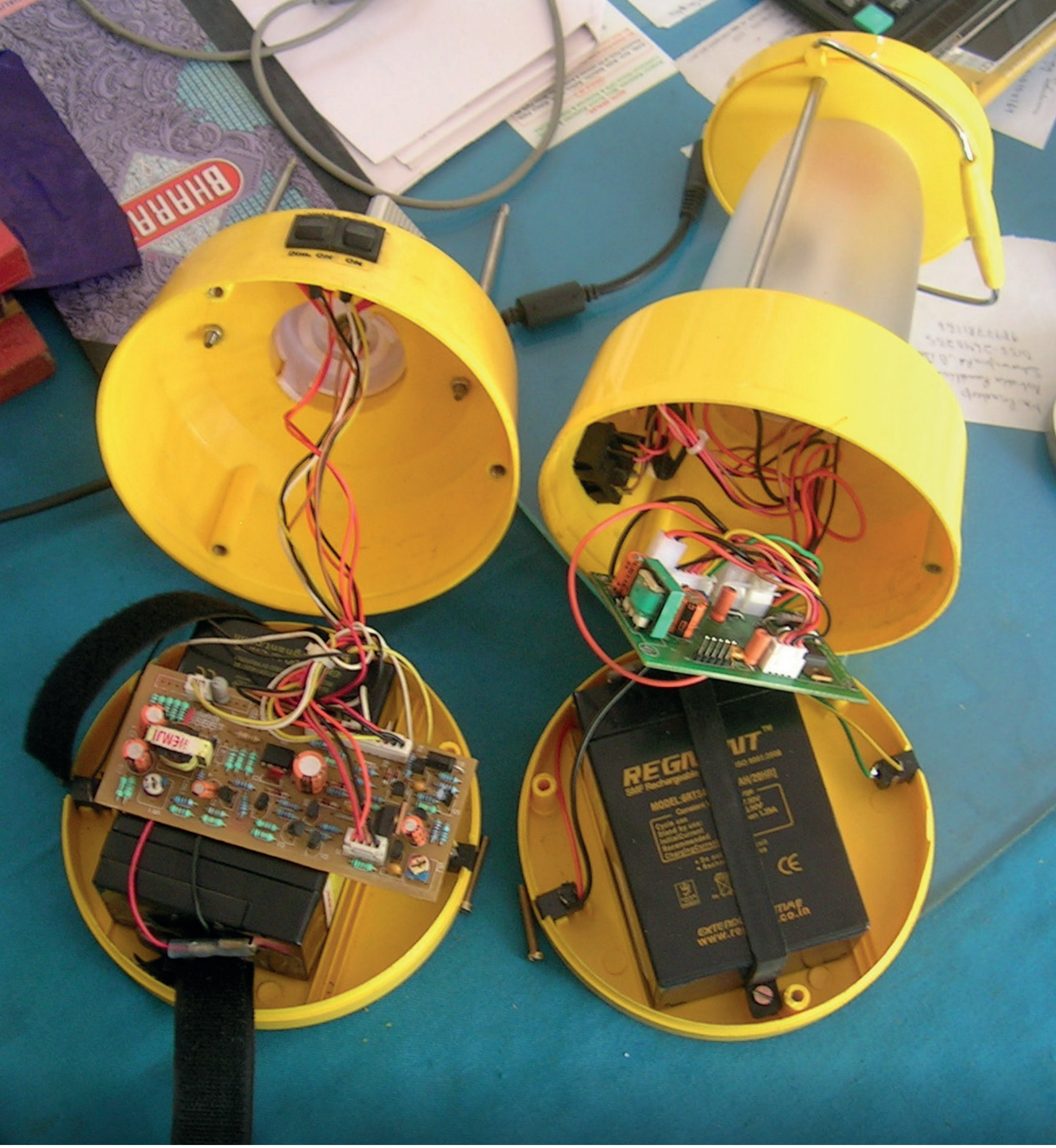
Murray, D.R. *Fixing development: breakdown, repair and disposal in Kenya's off-grid solar market.* PhD Thesis submitted to the University of Edinburgh, 2020.

OECD *Business Models for the Circular Economy: Opportunities and Challenges for Policy*, 2019, https://tinyurl.com/y4tffpd3

Raworth, K.. *Doughnut economics: seven ways to think like a 21st-century economist,* 2017, London: Chelsea Green Publishing.

Staub, L., *Off-grid Solar Products Going Circular: Exploring the potential for repair, refurbishment and remanufacturing strategies and business models for Solar Home Systems and Solar Lanterns in India.* IIIEE Master Thesis, 2019.

United Nations Environment Programme *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*, 2017, http://tinyurl.UNEP2017



CONTACT US

- efficiencyforaccess.org
- info@efficiencyforaccess.org
- @EforA_Coalition

Cover image and image on p36: Third party repair of off-grid solar products in Goudoubo Refugee camp (Burkina Faso). Copyright © Edoardo Santangelo.