Future Scenarios for Circular Management of Solar E-waste in Kenya: EPR-regulation and Beyond

Extended Policy Brief

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1. Introduction

This policy brief has been prepared based on a research conducted in the project titled *Governing solar electronic waste in Kenya*, undertaken in the period from 2021 to 2023. The project was funded by the Ministry of Foreign of Affairs of Denmark and was carried out through close cooperation between the Technical University of Denmark, University of Nairobi and Kenyatta University.

Kenya is a leading country in the transition to off-grid solar energy in Sub-Saharan Africa. Stand-alone solar home systems including solar panels, batteries, control units and electricity outlets bring out low-cost energy to millions of people in rural areas, which are not reached by the electricity grid. Today, it is estimated that 28 per cent of Kenyans have access to some kind of off-grid solar product. [1]

Off-grid solar products (hereafter 'OGSP') come in various packages and price levels, ranging from the smallest pico-systems that include only a *solar lantern*, over *multi-light systems* that provide electricity for more lights plus a mobile phone charger and sometimes a radio, to genuine *solar home systems* (hereafter 'SHS'). SHS have capacity and control unit outlets for additional appliances such as TV, speakers, hair dryer, and even refrigerators and water pumps for the largest systems. [2]

While providing for easy access to sustainable energy in low-income rural areas, the growing sales of OGSP and components have a downside referred to as "the dark side of the sun [3]. The downside is the huge amounts of e-waste generated by discarded OGSP. The solar home systems offered in Kenya today is estimated to have an average life span of about 4-5 years. The batteries often need to be changed after only 2-4 years [4,5], so the 4-5 years should be considered the time after which it does normally not pay-off to extend the lifetime of a solar home system.

In Kenya, efforts are devoted to design policies, and to invest in and establish solutions for management of the e-waste aiming at circular economy principles. However, while the newly adopted extended producer responsibility (EPR) regulation in Kenya is the first serious regulatory initiative to cope with the rising e-waste problem, it is only the first move that needs to be understood, assessed, developed, and supplemented, in view of three broader solution strategies for circular management of e-waste.

As part of the research conducted in the project, we studied three possible scenarios for improving solar e-waste management in light of the forthcoming EPR regulation in Kenya. Each of these three major strategies can be viewed as a solution scenario, each with their own infrastructure requirements, and each of them having different environmental, and other socio-economic consequences. All three solution scenarios classify as circular at different levels in the waste hierarchy, as they imply either waste minimizing or recycling beyond energy recovery. Moreover, all three scenarios are necessary to some extent and in some combination as, sooner or later, all OGSP reach an end-of-life stage where the value of resources become down-graded and hence must be put to their best alternative use.

In this policy brief, we present the main conclusions from our research and discuss what implications they have with respect to major regulatory instrument for handling EPR-waste, i.e. the EPR-regulation. We also discuss what is needed beyond EPR-regulation to ensure circular management of e-waste in Kenya and hence environmental improvements, while at the same time maximizing economic benefits for Kenya.

2. A multi-criteria decision-making framework for explorative assessment

To assess the prospects of the three different scenarios, we have established a multicriteria decision-making framework that allows for a *structured exploration* of their most important socio-economic consequences – without the intention to summarize the results into one final score. The major criteria and sub-criteria that we have used are shown in Table 1 below.

One major source of evidence for our exploration of the scenarios has been scientific literature as well as reports from governments and other organisations on the current situation in Kenya and the experiences so far with the respective circular waste management solution scenarios in both Kenya and other countries. Hence, existing literature constitutes the basis for our explorative analysis. Our second major source of evidence is observations from stakeholder workshops, semi-structed interviews, and a structured expert survey.

Based on stakeholder workshops in 2022, we formulated questions for, on the one hand, semi-structured interviews and, on the other hand, a web-based survey. The web-survey includes descriptions of the three scenarios, along with the context in which they should be interpreted, followed by questions related to their expected relevance, barriers, and socio-economic consequences.

Table 1: The criteria applied for exploring the impact of the three scenarios

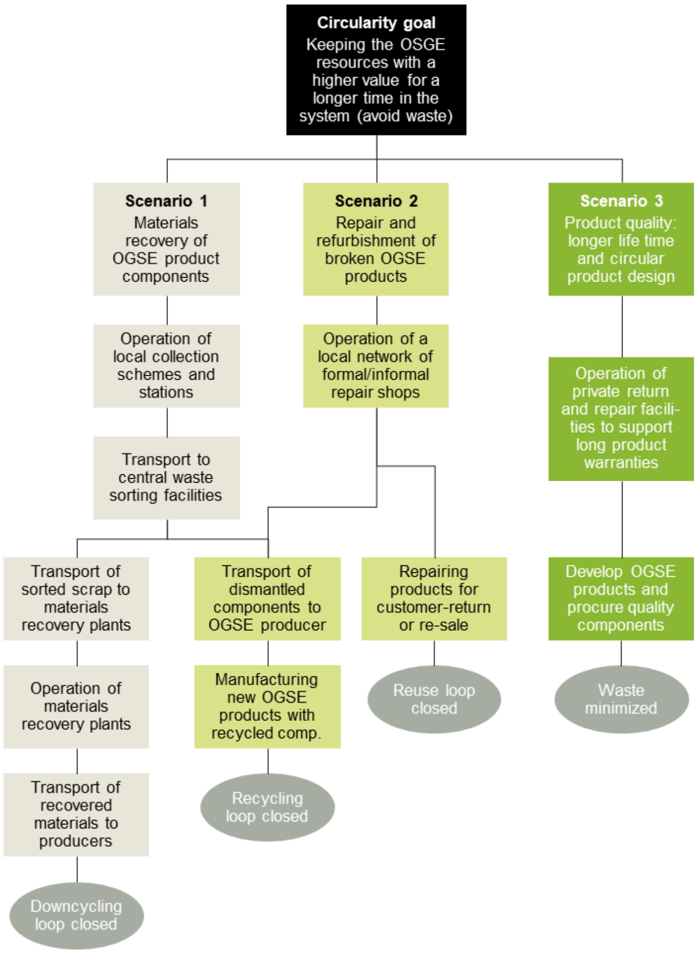
Overall	Criteria level 1	Criteria level 2
Socioeconomic impact	Environmental impacts	• GHG emissions • Toxic emissions
	Budgetary effects	• Government revenue • OGSP supplier profits • Waste company profits (formal sector) • Informal sector profits • Consumer prices
	Employment effects	• Employment in OGSP sector • Employment in waste & recycling sectors

It was answered by 20 targeted experts spread across the following stakeholder groups: government representatives involved in regulation of solar e-waste, representatives from waste recycling companies, representatives from GOGLA and OGSP suppliers (producers and retailers of solar home systems) plus university experts.

3. Preconditions and barriers for the scenarios

The primary objective of circular waste management is to deploy the resources (products/materials) to ensure the highest possible value for as long as possible in a circular system – without the resources going to waste. Applying the scenarios to the Kenyan context, each of them have their own set of prerequisites and barriers that need to be addressed to circulate as much of the resources as possible. As illustrated by Figure 1, Sc.1 involves the most stages and exchanges to keep a circular loop going, while Sc.2, and especially Sc.3, require smaller loops, and presumably also less transport and energy, but not necessarily fewer costs.

Figure 1: Basic scenario infrastructure



Scenario 1 – infrastructure and barriers

The scenario requires collection schemes and sites to hand in waste at the local level plus extensive waste transport infrastructure to get enough waste to the central waste sorting and materials recovery facilities. Today, all three main waste companies dealing with E-Waste in Kenya are situated centrally in Nairobi: Enviroserve, WEEE Centre, and E-Waste Initiative Kenya (EWIK). The value of the e-waste is not sufficient to cover the costs of collecting it, which is why all three waste companies are reliant upon partnerships with major electronics suppliers and end users plus informal collectors that have strong enough incentives to deliver the e-waste to the three companies [6,7].

The infrastructure requirements constitute a significant barrier, as it will be difficult and costly to set up a waste collection and transport infrastructure covering the rural areas. Transportation to central waste sorting facilities is not only costly, but also require fossil energy for land transport, especially from the more distant rural areas. Furthermore, the three central e-waste recyclers in Nairobi have not yet established sufficient own capacity, or arrangements with local materials recyclers, to safely dismantle and recover certain major e-waste components from OGSP. This entails very long transport distances, and a North-South split in the global value chain [8], when recovering materials from a substantial part of the e-waste

Scenario 2 – infrastructure and barriers

For the repair and refurbishment activities which are undertaken by the original suppliers (producers and retailers) of the OGSP, Sc.2 will require a rather extensive waste collection and transport infrastructure. This is because the suppliers in Kenya have, at most, regional repair and refurbishment centres, and in some cases only a central repair centre in Nairobi. These regionally- or centrally located repair centres are dependent on receiving products for repair from locally situated retail shops or service centres, where the customers can hand in the broken products. As a high share of OGSP customers come from rural areas it is challenging and costly for the suppliers to establish effective distribution of broken and repaired products.

However, as evidenced by Cross and Murray [9] and Samarakoon et al. [10], informal electronics repair shops and technicians (*fundi*) also play an important role in prolonging the lifespan or securing an afterlife of OGSP in Kenya. Informal repair is local, cheap and flexible, thus providing an alternative which is sometimes more attractive than the formal repair centres. First, informal repair shops and technicians provide an opportunity for fixing, or perhaps getting a small payment for, broken OGSP which are out of warranty. Second, it provides a quicker (and often less costly) alternative to fixing branded components that would otherwise have to be delivered to the supplier and transported to a distant repair centre. Hence, the informal sector contributes to keeping a relatively larger share of the OGSP resources circulating. The major drawback of the informal shops and technicians is that, too often, they disregard safe handling of harmful substances in the OGSP components which therefore ends up as hazardous waste in the environment. [11]

Sc.2 also have some barriers which is related to intrinsic conflicts over market share and authorized handling of products between OGSP suppliers vs. informal repair shops and technicians. The warranties of branded products become void if an unauthorized technician opens them, and therefore serve to exclude informal technicians from repairing such products within the first 12-24 months. In addition, the branded suppliers often deliberately provide for *black-boxing* and limited interoperability of their products. [10,12].

Scenario 3 – infrastructure and barriers

Sc.3 is about minimizing the generation of e-waste by ensuring longer lifespan of OGSP and facilitate re-circulating of components when the products reach the end-of-life (Eol) stage.

While a clear majority of OGSP in the Kenyan market are quality-verified and branded, a significant portion (up to 35 per cent) of solar home systems still lacks quality verification [1]. Moreover, the EED and VeraSol survey reported higher breakdown rates for the surveyed non-quality-verified products (solar lanterns 19 per cent, SHS 31 per cent) compared to the quality-verified ones (solar lanterns 9 per cent, SHS 9 per cent). Such differences suggests that verified products usually last longer. However, the average OGS product durability is not long. Our interviews with major OGSP suppliers indicate that a SHS usually lasts about 4-5 years before it is regarded unsuitable for repair. Yet, an initial breakdown – typically in batteries, switchers, or control units – often occurs sooner. [1,4,5]

Hence, there is still substantial potential for quality improvements in relation to maximizing product durability and recyclability, even for the quality-verified products. However, such improvements in quality will drive up costs and consumer prices for the products resulting in more Kenyan consumers not being able to afford them. This may have the unintended side effect of increasing the market share of cheaper, non-branded products that do not meet minimum quality standards.

Subsidies and regulation could be adopted to support product quality improvements, but the more regulated and expensive the products get, the risk that it may stimulate a grey market of OGSP suppliers that does not meet the legal EPR-requirements for registration, operation, and product sales in Kenya, becomes greater. Hence, the Kenyan income distribution, the competitive threat from non-quality-verified and non-branded OGSP, and the imperfect enforcement of product regulations, are some of the major barriers that may prevent Sc.3 from realizing its potentials.

Comparing the barriers and their relative strength

Overall, the strongest barriers apply to Sc.1 due the waste infrastructure barriers, and Sc.3 due the losses OGSP suppliers may suffer if they improve their products to "gold standards". It is important to keep in mind, why OGSP were introduced to the market in the first place. It was mainly to avoid the massive scale of infrastructure investments required for connecting rural areas to a central grid. Hence, recognizing that the main barrier to materials recovery and recycling (Sc.1) is similar in nature (if not scale) to that of establishing an efficient public grid, should at least direct the policymaker's attention to the prospects offered by the two other scenarios. However, as we have seen, there are also barriers to Sc. 3 – and even to Sc. 2, which in relation to the challenges of including the informal sector may require extensive funding and capacity-building.

4. Environmental impact of scenarios

From an extensive literature review of existing LCA-studies on solar energy products and systems, we found numerous studies that deal separately with either PV solar panels, batteries for PV-systems, or entire PV-systems connected to a public grid or a PV-minigrid. [13,14] Yet, we only found one relevant up-to-date study assessing the lifecycle environmental impact of a representative off-grid solar home system (SHS) in a rural area in Kenya: A study by Antonanzas-Torres et al. from 2021 comparing 16 different LCA-scenarios for an 80 Wp poly-crystalline PV module, a 60 Ah 12 V lead-acid battery, 10 m of 2.5 mm^2 copper wire, and a PWM charge controller. [5]

The LCA-results have some important implications for circular management of solar e-waste in Kenya:

1. By far the highest environmental impact stems from the manufacturing of the batteries, and their frequent replacement. Therefore, particular attention should be given to enhance the capacity for local recycling of lead-acid and other battery types, and to incentivize product quality improvements with respect to greener battery types and longer battery lifetime.
2. The production location of the solar home systems and their components, and the transportation distance between the production locations and the end users, have considerable implications for overall GHG emissions. Transportation distance is of even greater relative importance when looking only at the end-of-life management of OGSP, which is the central stage for our circular waste management scenarios. The LCA-results indicate that – in a country like Kenya, where materials sorting and recycling takes place far away from the rural user sites – waste transports may contribute with GHG emissions in the same order as the final recycling/disposal processes.

Hence, with the current formal waste treatment infrastructure in Kenya, materials recycling and recovery will entail considerable additional GHG burdens from EoI waste transport. This finding – together with the observation that most environmental impacts arise from the production of new batteries, PV-modules and charge controllers – leaves little doubt that Sc2. (repair & refurbishment) and Sc.3 (waste-minimizing product design) are environmentally superior to materials recovery (Sc.1).

Even if we add credits for recycled materials, this will not change the conclusion. Materials recovery can only compensate for a small fraction of total GHG burden from producing and delivering the solar home system. One reason for this is that the production of PV-modules and batteries is rather energy intensive. In fact, the GHG impact from the process energy required to produce the components are much higher than GHG impact from producing the materials on which they are based. The other reason is that the recovered materials are normally downcycled to a secondary materials market rather that entering a closed loop of the PV- and battery manufacturers.

The problem of unsafe treatment of hazardous waste from OGSP within the informal sector is not quantified in the existing LCA studies due to the limited focus on African conditions and the lack of empirical datasets representing such informal practises. [14] Yet, from other sources of evidence, it can be concluded that, in African- and other developing countries, e-waste containing hazardous substances is much too often dismantled, burned, and dumped by scavengers, small-scale recyclers, and refurbishers in ways that the result in highly toxic emissions. [11,15,16,17] Hence, to allow the actors within the informal sector to play a role in implementing Sc.1 and Sc.2, they should be trained and supported to acquire the necessary competencies and technical capacity to treat the solar e-waste in environmentally safe ways.

Table 2. Overview of economic risks and opportunities associated with each scenario

Impact category	Sc.1: Materials recovery		Sc. 2: Repair & refurbishment		Sc. 3: Waste-minimizing product design	
	Economic risks	Economic opportunities	Economic risks	Economic opportunities	Economic risks	Economic opportunities
Government spending and revenue	Will be very costly for state and regions to establish the necessary waste collection and treatment infrastructure	By introducing EPR regulation part of the financial burden for waste infrastructure can be shifted to OGSP suppliers	Government incentives/ subsidies necessary for strengthening capacities of fundis (the informal sector)	*Uncertain how enhanced repair & refurbishment of OGSP will affect net tax revenues*	If this is pursued via regulatory standards it will entail high enforcement costs (and maybe a growing grey market)	Higher products quality implies higher product prices and (all else equal) a potential or higher tax revenues
OGSP supplier profits	EPR require-ments to collect OGSP waste equal to new products put on market will greatly increase the costs of suppliers	Such EPR requirements will create some entry barriers and hence be an advantage for established suppliers	Strengthening the capacity for formal repair & refurbishment will require new investments by the suppliers and the sale of new products is likely to decrease	There is some unrealized potential to make profits from second-hand refurbished products	Improving product lifetime (e.g. via more durable LI-ion batteries) and recyclability make products more expensive and hence risks of losing market shares to grey market products	More focus on and better eco-certification of product quality create profit opportunities for suppliers with sustainable products
Waste collection and recycling company profits (formal sector)	It will require considerable investment in local recovery plants & facilities, the proifts of which are sensitive to secondary materials prices	Revenues and profits of Kenyan waste collection and recycling companies are expected to surge in case a high share of OGSP waste is collected and recovered	Waste collection and recycling companies will not benefit as much by Sc. 2 as by Sc. 1, since a higher repair rate means less OGSP waste	Waste collection and recycling companies could, however, make profits from refurbish-ment as this is not reserved for the supplier repair centres	On the one hand, more durable products mean less waste and hence reduced revenue and profit potentials for the waste companies	On the other hand, improved product design that makes it easier to dis-mantle & reuse components may increase revenues and profits of recyclers
Informal sector profits	An EPR regime will put pressure on suppliers to collect much OGS waste. It might reduce the waste stream to fundi (repair shops)	If some informal actors within waste collection or recycling are integrated (i.e. are allowed to operate by the EPR rules), they may experience rising net profits	The regulatory provisions and incentives to repair & refurbishment might to an increasing extent cut off fundis from playing a role	Provided the regulation allows fundis to play a role, and that their capacities and skills are improved, they may greatly profit from Sc.2	same as above	Same as above
Consumer prices and benefits	The burdens from financing waste handling (e.g. EPR fees & investments) are likely to be shifted into higher OGSP prices or taxes	The suppliers are likely to pay the consumers for turning in more waste via discounts on new products and other incentives	*Improving capacities for OGSP repair & refurbishment entail* NO MAJOR RISKS *for consumers expenses*	Improved access to repair & refurbishment means less time and costs spent on handing in broken products and less money spent on new	Higher prices must be paid up front for the quality improved products	The lifetime net value to the consumers could be higher if the products are better and last longer
Employment (in Kenya)	A part of the employment effect will not take place in Kenya since some of the materials (still) need to be recovered abroad	Employment in Kenya expected to grow signifi-cantly as many new jobs will be created in local collection, transport and recovery of waste	If regulatory provisions and incentives to repair & refurbishment cut off fundis, employment may drop in the informal sector	Employment in Kenya expected to grow signifi-cantly as many new jobs will be created in repair & refurbishment of OGSP	Since the vast majority of OGSP are still designed and manufactured in the Global North no or little employment effect is likely in Kenya	Product design that makes it easier to dis-mantle & reuse components may have some employment effect for local waste recycling

5. Economic impact of scenarios

Table 2 on the former page summarizes the main conclusions from our workshop sessions and interviews on the expected economic consequences of each scenario. The Table lists some of the most important economic risks and opportunities in relation to each of the economic sub-criteria under the main criteria; budgetary effects and employment effects.

From the viewpoint of national economy, the employment effects in Kenya are arguably the most important macroeconomic consequence following from the the respective scenarios. A central question is the extent to which the implementation of the respective scenarios will stimulate Kenyan employment vs. employment in foreign countries. Especially in the case of Sc.1 there is considerable risk that Kenya will not succeed in building sufficient capacity for advanced materials sorting and recovery, and in that case much of the growing volume of collected solar e-waste will be exported to other countries with more advanced treatment facilities. Then a relative high share of the additional jobs would be created in the Global North.

However, much of the waste collection and treatment infrastructure required for implementing Sc.1 would have to be established locally, and at regional and central locations, within Kenya. Therefore, the implementation of Sc.1 is quite certain to generate a rather strong positive employment effect. But the strength of the effect depends on the extent to which Kenya succeeds in building more national capacity for advanced materials sorting, recovery, and recycling. Sc.2 is also quite certain to generate additional employment in Kenya. Moreover, there seems to be less risk that the new jobs will be created in foreign countries when it comes to enhancing the capacities for repair and refurbishment of OGSP.

Interviews with stakeholders and the literature confirm that the global value chain is organized in a way that repair and refurbishment of OGSP (and many other electronic products) is being carried out almost exclusively in Kenya - despite the original products being supplied mainly from China and other countries in the Global North [[3],[8]]. Hence, there is every reason to assume that the expected growth in repair and refurbishment activities from implementing Sc.2, including growth in the trade of second-hand products, will happen in Kenya. Moreover, if the informal sector, not least the *fundi*, are allowed and capacity-enabled to play a substantial role in implementing Sc.2, the employment effect would likely be strengthened and spread out to local communities throughout the country.

6. Discussion of policy implications

6.1 EPR-regulation is a step forward, but unsolved challenges remain

With the completion of the final draft for new *e-waste regulations*, including the introduction and regulation of extended producer responsibility (EPR), Kenya has taken an important step in the direction of circular management of e-waste. [[18],[19]] Introducing the notion of EPR, the new regulation mandates that all *producers* of electrical and electronic equipment shall, *inter alia,* apply for registration, account for the amount of electrical and electronic equipment products they introduce to the market each year, provide information to recyclers on how to dismantle their product at the end of life, and disclose the location of any hazardous substances or items within the product. Moreover, producers shall support the financing of collection and treatment for problematic fractions by a licenced *treatment facility* to ensure effective take-back and treatment of e-waste.

Producers include not only manufacturers, but also importers, distributors, and assemblers of electric and electronic equipment. *Treatment facility* refers to a "licensed plant, premise, and establishment for processing e-waste" thus implying that to fulfill their take-back responsibilities, the producers must establish contractual arrangements with licensed e-waste processers. The contractual arrangement could be either collective, where more producers form an organization (a PRO) which enter contracts on their behalf with one or more e-waste processers to fulfil their joint obligations, or the producer could make an individual arrangement with an e-waste processer. The contracted treatment facilities will incur costs from collecting, sorting and treating the e-waste. Treatment may consist in either repairing, refurbishing, dismantling, recovering, or leaving it to third-party recyclers for recycling or safe disposal.

It should be noted that new regulation provides that "every producer (and hence also the contracted treatment facilities) "shall ensure that e-waste returned under individual take-back schemes, is not disposed of at a municipal disposal site/facility". The regulation generally prohibits the use of public waste treatment infrastructure for e-waste hence leaving the entire financial burden for the e-waste being collected to the producers.

The costs of e-waste processing, and the reimbursement by each producer, will be calculated annually by the National Environment Management Authority on basis of evidence notes from the licence treatment facility, and the relative market share of the producer according to the reported sales. Hence, the public authority will determine the EPR fees to be paid each year by each producer. The regulation also provides that the total amount of electrical and electronic equipment put on the market, the total amount of collected and treated e-waste, and the overall EPR-compliance rate (in which the latter amount is divided by the former), will be calculated and registered annually.

Yet, it is remarkable that the regulation does not specify the consequences – if any – in case the annual EPR-compliance rate turns out to be significantly lower than 1. This ambiguity, together with negative value of much e-waste on the Kenyan market (i.e. when the intrinsic material/use value of the waste is lower than the collection and processing costs), questions the strength of the producer incentives. The more e-waste being collected among the less valuable fractions, the higher EPR fees to be paid by the producers. Of course, the licenced treatment facilities could be said to have an interest in collecting and treating as much as possible as the producers are obliged to cover their documented costs, in any case. Yet, they may be vulnerable to losing their contract unless they act in the interest of the producers.

Another challenge with the drafted e-waste regulation is that it rules out informal activities being performed in collecting and treating e-waste. The current informal waste collectors and small-scale recyclers could still, in principle, be sub-contracted by the contracted treatment facilities and hence play a role in enhancing the collection and recycling rates. However, under the new regulation, they are not allowed to be involved in such activities unless they are formally approved as recyclers or waste transporters.

To be allowed as recycler requires an application for operating in this capacity including a complicated license for environmental impact assessment which will be far too difficult and costly to achieve for most small-scale recyclers. If the new provisions are strictly enforced (which is not certain given Kenya's previous track record in enforcement), it will effectively cut-off a high number of existing informal waste collectors and recyclers for whom it will be too difficult to fulfil the requirements for formal approval. That would reduce the overall capacity and add to the problem concerning the producers lack of incentive to collect enough e-waste fractions with negative value.

The new e-waste regulation does not prevent repair by informal repair shops and *fundi* as they are classified under "refurbishment" for which no new licensing procedures are required. The product-life-extending services performed by repairers/refurbishers are not, as such, e-waste processing. But it does generate e-waste as a by-product, and the new regulation therefore stipulates that all refurbishers must keep track of the e-waste they produce, and that they shall bring it to licenced collection centres and recyclers. This provision will hopefully contribute to a greater share of that e-waste being recycled or disposed properly.

Although the new regulation stipulates that the recyclers, as part of their licensing requirements, shall "give priority to the refurbishment of used electrical and electronic equipment to increase its working life before dismantling for recycling purposes, material recovery or reprocessing", the regulation is clearly focused on management of end-of-life products having become e-waste. It mainly addresses the producer's responsibility to collect the e-waste and ensure that as much of the materials as possible are recovered, or at least safely disposed. In that sense, the new e-waste regulation is a legal means to facilitate the implementation of Sc.1, by providing full responsibility of the producers to build and finance the necessary waste infrastructure and treatment activities for implementing such a scenario.

While this may be in line with the polluters-pay-principle, the regulation evades the question on whether it is realistic that the producers will be able and willing to finance a separate e-waste infrastructure from scratch, given the lack of existing waste collection and transport infrastructure to rely on. In most developed countries with EPR-regulation, the producers can rely on an already well-functioning public waste collection infrastructure. For example, a dense network of public "recycling stations" where households and certain small enterprises can hand in all sorts of e-waste.

According to our interviews, the perception in the Kenyan government seems to be that the producers must cover all costs of e-waste processing, including all investments in building the waste infrastructure from scratch, via the annually calculated EPR-fees. We argue that this is hardly a realistic assumption. Refraining from any public investments in the general waste collection infrastructure that could also benefit e-waste, and banning all e-waste from any public funded sites, will only accentuate the adverse incentive of the producers to not collect sufficient e-waste with a negative value.

6.2 Recommendations for the further implementation of the EPR-regulation

Despite some deficits elaborated in the section above, the draft e-waste regulation introducing producer responsibility for e-waste in Kenya is an important legal and institutional milestone which will commit OGSP suppliers and other producers of electric and electronic equipment to organize and invest in circular e-waste management. The new regulation will stimulate efforts to implement Sc.1 (materials recovery from solar e-waste).

Depending on how the details of the policy implementation are settled, the new rules may, or may not, stimulate efforts to repair OGSP. The OGSP suppliers must document that the contracted treatment facilities collect and process as much solar e-waste as the weight of OGSP put on the market. If repairs are not accounted for as processed e-waste, because it does not enter the waste stream of the treatment facilities and their sub-contractors, it will not count in the EPR-compliance rates. It is therefore important that the guidelines for implementing the regulation specify how to account for repairs so that they count positively in the compliance rates. Otherwise, there will be an adverse incentive to channel more solar e-waste into the waste stream rather than repairing it.

We also recommend that it is clarified what the consequences will be in case the suppliers fail, individually or collectively, to collect and process as much e-waste as they bring to the market. This very important matter is not specified in the current draft. Moreover, we conclude that more policy efforts and public investments are required to build a public waste infrastructure that also supports the collection and transportation of e-waste. As we argued, it is not realistic that the producers are able or willing to build a waste infrastructure from scratch, that provide for effective waste collection at the local level; it would result in huge EPR fees that would deter many suppliers from engaging in the market.

Finally, we recommend that much more should done to integrate and mobilize the informal sector in circular management of OGSP and solar e-waste. As it stands, the new e-waste regulation mainly has the effect of banning informal activities and illegal practises in handling e-waste. While the banning of illegal practises is necessary, the government should come up with solutions on how to avoid that local collection and small-scale recycling activities and employment drop in consequence of the strict formalization requirements contained in the new regulation. The only way to avoid that, we argue, is by integrating the informal sector via lenient, non-bureaucratic means to gradually formalize and legalize the former informal activities. That means finding other and more suitable ways than a complicated environmental impact assessment certification scheme to authorize recycling activities – and combine it with strong capacity-building efforts.

Capacity-building of the informal sector – in particular subsidized training and certification schemes for informal repair shops and *fundi* – is also the way forward to promote the implementation of the environmentally superior Sc.2. The new e-waste regulation does not really address how to ensure that repair and refurbishment is promoted and given priority to materials recovery and other waste handling. In our view, new policy initiatives are needed which provide means to mobilize and enable actors within the current informal sector to ensure that environmentally safe repair and refurbishment of out-of-warranty OGSP is, to an increasing extent, being carried out at the local level, close to the OGSP consumers. Hence, the prevention of local e-waste streams should always be given priority over complicated and energy-intensive e-waste processing activities.

6.3 Making further progress beyond EPR-regulation

The current thinking and waste management policy strategies in Kenya and other SSA countries put much emphasis on collecting and recycling the materials contained in the e-waste and less emphasis on repairing or improving the products. [12] Such an industrial recycling strategy is known to work, often with the help of developed countries capable of importing and recovering waste fractions which require advanced mechanical or chemical treatment. Based on our assessment of barriers and impacts associated with Sc.1 we argue that the current focus overlooks: (1) the scale of barriers in setting up a well-functioning country-wide waste collection system in Kenya; (2) the environmental problems in transporting too much waste over too long distances, and (3) the risk that much of the employment and growth effect would materialize outside Kenya.

We therefore argue that relatively higher environmental benefits, along with greater economic advantages with respect to employment and distributional effects in Kenya, could be achieved if Kenya devotes relatively more resources over the coming years in pursuing a repair & refurbishment solution scenario (Sc.2) compared to a materials recovery scenario (Sc.1).

Scaling up and improving repair and refurbishment will extend the life of OGSP thus creating less waste that needs to be transported and treated, and hence provide greater environmental benefits than materials recovery. Whether this will succeed, and whether it will also be better for Kenya from an economic perspective, depends to a large extent on whether it proves possible to mobilize and enable the informal sector to perform environmentally safe repair, refurbishment, and disposal of OGSP. Building this capacity will require new incentives, institutions-building, and scaling-up of training programmes for the informal sector.

The investments required for that are not likely to come from the OGSP suppliers. The OGSP suppliers are going to invest in their own repair centres plus their own collection and recycling of e-waste, while they might consider sourcing parts of their activities to informal actors that succeed in getting a formal licence. The financial resources for capacity-building of the informal sector must therefore come mainly from the government, donors, and socially oriented formal e-waste recycling companies (the latter are already engaged in training informal actors).

The relative priority given to Sc.2 does not mean that OGSP suppliers and the government should refrain from investing in better waste infrastructure and materials recycling capacity in Kenya (Sc.1). While economies of scale, technical challenges and investment risks associated with materials recovery are generally high, a growing need for materials recovery of end-of-life parts that cannot be repaired or refurbished will result from the growth in off-grid solar energy. To achieve socio-economic benefits from the materials recovery scenario, we argue that Kenya should, as far as possible, aim at supporting sufficient, residual local capacity for materials recycling of e-waste - even if the plants need to be built on a smaller scale than the most efficient recycling plants in the global North.

From an environmental point of view, Sc. 3 (waste-minimizing product design) will be preferable to any of the other two. Yet, high-quality recyclable products with longer life span also means more expensive products, and hence a risk that Kenyan consumers will turn more towards non-branded products that do not live up to such standards. Moreover, as most of the products are imported from foreign producers in the Global North and China, it is not certain that the Kenyan economy will benefit much from intensified efforts among producers to manufacture products with longer life span and improved circular design for the Kenyan market. Much could also be gained from better guidance in use and maintenance of existing OGSP which often break down due to inappropriate use. [20]

However, future efforts to promote waste-minimizing product design should not be ruled out due to these reservations. First, OGSP and their components continually develop in the direction of offering greener solutions, and making such solutions more affordable, due to preferences, regulation, and demand dynamics on the world market. Hence, new product regulations and standards could be introduced in Kenya which tap into this technological development without necessarily aiming to be at the forefront. Second, there is the opportunity that more of the OGSP manufacturing, including assembly and production of PV-modules and batteries, could be relocated to Kenya in the future. In that case, the superior environmental benefits of the waste-minimizing product design scenario might also go hand in hand with employment and other socioeconomic benefits for Kenya.

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