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The solar repair trade in Nairobi (Kenya): the blind spots of a “sustainable” electricity policy

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1 The lobby to the headquarters of a market leader in domestic solar kits in Kenya has a framed photo hanging on the wall of Barack Obama visiting the premises. On another wall, a screen shows a short film of a visit by technicians to Machakos, in the region of Luhya. Visitors may see a shop of the company’ products, and installations of solar kit powering equipment (TVs, fridges) and small businesses. A user explains that he increased his revenue thanks to the company’s products, enabling him to pay for his children’s studies. These few examples encapsulate the success story of photovoltaic solar power (PV) in Kenya: a clean technology giving access to electricity and supporting economic activity. Solar electrification solutions indeed hold out the hope of eco-friendly development, both in Kenya and sub-Saharan Africa more generally (IRENA, 2019). But when we examine this narrative in the light of how the solar industry is organised in Kenya, we may see tensions between largely incompatible objectives: affordable equipment, supporting local employment, and environmental sustainability. This article discusses these by analysing maintenance and repair activities for PV equipment. Our hypothesis is that such activities may be used to assess the extent to which electrification policies are socially responsible (by consolidating local employment sectors) and environmentally responsible (by reducing waste). Conversely, the marginal place of solar repairs in Kenya’s electricity value chain raises questions about the main objectives of an industry presented by international bodies as ecological (Lighting Global *et al.*, 2020; IRENA, 2019).

2 What happens to broken or malfunctioning equipment? To what extent does it feed into the local repair and recycling industry? How are these activities managed, and by whom? To what extent does the sale of individual PV equipment to households, especially poor households, respect the socio-environmental objectives trumpeted by

the industry? As part of the Hybridelec research project,[1] looking at emerging forms of energy transition in Southern cities, a qualitative field survey was conducted in Kenya in January and February 2020, comprising thirty or so semi-directive interviews with independent technicians or those working for the main companies in solar, with various institutions involved in regulating the sector, and with electronic repairers in the informal economy. The purpose was to identify the actors and urban places where solar equipment is repaired, the value chains and their employment dynamics, and their recycling practices.

3 Unlike many works looking at the technical and economic aspects of renewables, which often display pronounced technological determinism, our analysis draws on literature in the social sciences analysing the role of political and socio-cultural factors in the socio-environmental sustainability of local energy transitions. We adopt socio-economic and socio-technical approaches, applied to the African urban context, to examine an overlooked aspect in the rapid spread of domestic-use solar energy in sub-Saharan Africa, namely maintenance and repair (Cross & Murray, 2018). By comparing the contrasting results how solar has been implemented with general employment and environmental expectations for solar, we set out to show the interest of "provincialising [...] debates" (Arik *et al.*, 2019: 108) and, more broadly, of developing a critical and situated approach to the energy transition.

4 After a review of the literature on solar repair and a presentation of Kenya's solar electrification policy, the article analyses the solar equipment market's limited knock-on effect on local maintenance and repair employment, showing that this results both from dominant firms being wary of (informal) local self-employed technicians and from the negligible place of repair services in these companies' business models. It then shows that the fact that solar equipment increasingly includes disposable microelectronic components compounds the environmental damage done by an industry producing increasing quantities of waste—especially e-waste—given that it is not satisfactorily managed. The conclusion examines the ambiguities of Kenya's policies to support solar electrification, torn between the goal of "sustainable" development driven by a low-carbon energy transition, and a strategy, dominated by philanthrocapitalism, to install individual equipment in poor households (Bishop & Green, 2008).

1. Solar repair: a forgotten aspect in Kenya's energy transition?

5 The dossier in *Afrique Contemporaine* on energy in Africa highlights that the continent has abandoned Keynesian policies, points out that various countries are racing to secure foreign private capital, and emphasises the supposedly apolitical vision international organisations have of Africa's energy future (Cantoni & Musso, 2017). The example of Kenya illustrates the role played by these organisations and how their targeted financing has influenced the development of a low-carbon electricity market. This is one illustration of the capitalist accumulation dynamic at work in the electricity sector as analysed by McDonald (2012), who refers to a "new scramble for Africa". Although the literature tends rather to mention major projects for power stations and network infrastructure, the individual electrification sector is also an attractive domain for investors, raising many questions about the quality of the equipment

proposed, especially domestic solar kits for low-income populations, and the resultant inequalities (Cross, 2018; Francius *et al.*, 2017). Hence this article looks at activities to maintain, repair, and salvage PV equipment (including their electronic components), and examines whether such activities contribute to the sustainability of Kenya's electricity transition in both socio-economic terms (by creating jobs, developing local value chains, and ensuring continuity in the supply of spare parts) and environmental terms (waste management).

1.1. A social sciences approach to solar technologies and their local urban ecosystem

6 Kenya has opted for an electrification policy partly based on PV equipment for poor houses and/or those far from the national grid. For many authors, and despite a dearth of literature on sub-Saharan Africa (Cantore *et al.*, 2017; Shirley *et al.*, 2019), the benefits of PV extend beyond electricity supply. Solar technologies are said to produce lots of jobs, half of them in maintenance and operation activities (Ram *et al.*, 2020; IRENA, 2019; Meyer & Sommer, 2016; Van der Zwaan *et al.*, 2013). Many studies have shown the positive health and economic effects of pico-solar equipment for households (purchasing less fuel, additional income from working at night, reduced exposure to toxic fumes, etc.: Jacquemot & Reboulet, 2017).[2] Lastly, they emphasise renewables' contribution to the post-carbon transition and hence to protecting the environment.

7 However, this final point is open to discussion. Just like the roll-out of the digital economy (Gabrys, 2013), deploying PV consumes rare materials, produces large quantities of e-waste, and—given the current state of recycling techniques—engenders many "irrecoverables" (Guitard *et al.*, 2019). In Africa, these risks are worsened by the fact that waste management is generally very insufficient and poorly managed (Jaglin *et al.*, 2018). And it is known that the deployment of solar kits may have a very negative impact on the local environment if waste is not processed, especially batteries composed of toxic products. Various studies have further explained that pico-solar products intended for the "bottom of the pyramid" are often poor quality. These products, designed to be as cheap as possible, are ill-suited to repair and generate much waste (Bensch *et al.*, 2017), a problem for which centralised recycling practices still fail to provide any appropriate solutions. Thus in Kenya, the strategy founders on the high cost of collecting defective or broken components, of little unit value and dotted across a vast territory (Cross & Murray, 2018). Cross and Murray suggest dropping the idea of end of life in favour of afterlives, showing that many apparently non-functioning objects find new uses via repair and recycling by self-employed technicians. According to them, these are the most sustainable decentralised solutions for managing solar waste products. In other words, though it is essential to plan for managing end-of-life solar components and equipment (Magalini *et al.*, 2016), it is even more crucial to privilege repairability given that these are societies with low financial and technological means in which material constraint is a necessity (Jaglin, 2019). The few studies of solar repair which do exist nevertheless emphasise organisational difficulties due to uncertainty about the environmental responsibility of each agent in the value chain and its low or non-existent profitability (Hirmer & Cruickshank, 2014).

8 Here the idea of repairability is central, and has been explored in many works examining the lifespan of technical objects (Appadurai, 1988; Bromberger & Chevallier,

1999; Wateau, 2011) and repair activities (Cross & Murray, 2018; Joulian *et al.*, 2016; Radjou *et al.,* 2013). In their exploration of the social, energy, and political issues raised by repair and scrap, Joulian, Tastevin, and Furniss insist on the role played by waste workers—"makers, hackers, doer-uppers, sellers-purchasers of second-hand objects, and antiques dealers” (2016*:* 23)—, their social organisations, their know-how, and their patching things up in response or even resistance to overproduction and programmed obsolescence. Bartholeyns, Tastevin, and Vallard (2019), for their part, emphasise a key condition for repairability, namely that a technical object be “composed”, that is, made up of several components and hence “open”, unlike the many “closed” products which, in theory, cannot be repaired. Grimaud, Tastevin, and Vidal also analyse the importance of maintenance activities, the “prototypical low-tech solution” (2017: 17), and the role played by repairs in “creolising” technologies and adapting them to local needs and uses. Just as in proto-industries founded on the waste economy (Lepawsky, 2018) and self-employed sectors appropriating transport technologies—as so well illustrated in Tastevin’s study of autorickshaws (2012)—, these works illustrate the central role of the technical expertise of local, largely self-taught technicians and the “open” nature of technologies in developing a local fix-and-mend economy.

9 Building on these studies, our work on the urban economy for the repair and maintenance of solar products in Nairobi examines how this relates to questions of employment (developing a *fundi* trade alongside consumer basins) and the environment (organising local collection, reusing and recycling broken or obsolete components). Focusing on what is currently the largest national market for off-grid solar products in Africa, we analyse, first, the jobs created/destroyed by competition between informal local technicians and the large companies dominating the market, and, second, changes in repair and reuse practices, in competition with less frugal approaches based on replacement. Indeed, although renewables make it possible to produce electricity where it is consumed and are therefore associated with the idea of relocalisation, domestic solar kits—the main driver in Kenya and elsewhere in sub-Saharan Africa—are primarily associated with international philanthrocapitalism (Bishop & Green, 2008) and a globalised industry (Cross, 2019). Examining maintenance and repair activities in Nairobi thus provides a way of examining the place left to local agents in value chains, depending on the technologies privileged, and on distribution networks and ways of managing product life cycles.

1.2. Kenya as a model for energy access and the development of the solar market

10 Kenya is often cited as an example for electricity access in Africa. In 2018, the country’s capacity stood at about 2800MW, of which 2000MW came from renewables. Among these, hydroelectricity and geothermal energy accounted respectively for 830MW and 660MW, while wind power generated 340MW and solar power 100MW.[3] In terms of electrification, the national average had progressed considerably, and by 2018 75% of the population—84% in towns and 72% in rural areas—had access to a service equivalent or superior to Tier 1, that is, at least four hours’ lighting per day.[4] Since 2015 the network has also become more reliable (Taneja, 2017): the average number of outage hours per consumer per year dropped from 188.5 in 2016 to 60.1 in 2019, and the average number of outages per consumer per year from 52.5 in 2015 to 13.3 in 2019.[5]

11 This progress results from ambitious policies. Under its Least Cost Development Plan 2011-2030, the Kenyan government has worked to develop renewables, especially via tax incentives, to increase its energy independence, and to cut back its dependence on oil (Republic of Kenya, 2011). This objective was restated in the 2019 Energy Act which emphasises promoting local skills to make, install, repair, and maintain renewable technologies, with the objective of affordable electricity for all Kenyans by 2030. A 5% tax on all electricity consumed in the country is also in place to finance the rural electrification program (Republic of Kenya, 2019). The Ministry of Energy and Petroleum (MoEP) runs two programs to achieve universal electricity access: the Last Mile Connectivity Project, carried out by the Kenya Power and Lighting Company (KPLC) to extend the national grid and connect households;[6] and KOSAP (Kenya Off-grid Solar Access Project), financed by the World Bank, and jointly implemented by KPLC and the Rural Electrification Agency (REA), to electrify off-grid regions outside the Mombasa-Nairobi-Lake Victoria central corridor where national infrastructure is concentrated.[7]

12 Propelled by international organisations, the Kenyan administration has fashioned an environment to facilitate market players: the Kenya Bureau of Standards (KEBS) has established standards for solar products;[8] the Energy and Petroleum Regulatory Authority (EPRA) certifies companies and technicians authorised to install solar equipment; and the government provides effective support for the market via a favourable tax policy. Investors have arrived, attracted by Kenya’s incentivising regulatory framework facilitating private companies, and the high penetration of mobile phone payments (Lighting Global *et al.*, 2020). The solar market, driven as of the 1970s by institutional demand (from schools, health centres, NGOs, etc.), then developed with the rise in domestic demand in the 1990s, initially for media use (radio and television) and then for lighting and for recharging phones. In the early 2010s, domestic solar kits accounted for 75% of the solar market, with a total capacity of over 10MW peak (Ondraczek, 2013). With 32 million potential users (George *et al.*, 2019), this remains a very attractive market. In 2018 it was one of the most developed in the world, with 5.6 million off-grid solar products and 31% of PAYGO sales (Lighting Global *et al.*, 2020).[9] It is dominated by a small number of companies, the ten largest of which accounted for nearly 80% of worldwide investment between 2012 and 2019 (*idem*), seven of which are active in Kenya (see table 1).

Table 1: Main companies involved in electrification in Kenya

Name of company	Year founded	Headquarters
d.Light	2007	San Francisco (US)
M-KOPA	2011	Nairobi (Kenya)
BBOXX	2010	London (UK)
Mobisol	2010	Paris (France) owned by ENGIE since 2019
Greenlight Planet/Sun King	2008	Chicago (US)

Azuri Technologies	2012	Cambridge (UK)
SolarNow	2011	Nijmegen (Netherlands)

Sources: d.Light; M-KOPA; BBOXX; Mobisol; Greenlight Planet; Azuri Technologies; SolarNow.

13 Nevertheless, Kenya's solar market is not comprised solely of domestic solar kits for new, mainly rural consumers (15% to 20% of households are said to be equipped: Jacquemot & Reboulet, 2017). There is a second solar market segment for clients who already have electric power, combining solutions to secure supply and to optimise expenditure (Rateau & Jaglin, 2022). It is composed of well-off urban households and industrial or commercial establishments (factories, shopping centres, petrol stations, hotels) which install PV panels on their roofs, and/or solar water heaters since the adoption of a favourable tax and regulatory framework in 2012 (Ondraczek, 2013).

2. Solar repair: a centralised activity closely controlled by the main players in a globalised industry

14 For both market segments, most of the technology is imported. Good-quality products come from European or US companies (British or US solar panels, Dutch or German inverters, etc.),[10] even if they are often produced in China. They are sold to clients who already have electricity, with sound financial capacity, thus less sensitive solely to price and more to quality standards and to lifespan. Cheaper middling and low quality products are often produced by Asian and especially Chinese, Indian, and Taiwanese companies. They are used either by companies supplying the already electrified segment to expand their range of prices and to adapt to their clients' differing criteria, or by companies in the electrification segment operating at the bottom of the pyramid (BoP). For example, a 2000W inverter made by a low-end Indian brand costs about KES40,000, as against KES90,000 to KES150,000 for mid-range and high-end equipment of the same power. Kenya produces little in the way of components for solar installations. Chloride Exide is the only company to produce lead batteries locally, while the Solinc factory in Naivasha, to the west of the capital, makes low-capacity solar panels (of 15W to 320W) used by companies selling solar kits, especially M-KOPA. Thus with a few exceptions, the companies on Kenya's solar market depend on foreign manufacturers for equipment and spare parts.

2.1. Repairs: heterogenous practices and know-how

15 Most requests for repairs are for inverters or controllers for domestic solar kits. Inverters may break down due to overheating, caused by dust, animals, or insects, damaging the circuits. They may also result from faulty installation, especially when the equipment does not correspond to the installed capacity. Batteries are not repairable, and their lifespan is reduced if the battery is discharged entirely. Lastly, solar panels have a theoretical lifespan of about 25 years, but may be broken, by people throwing stones for example,[11] and are not repairable.

16 Most repairs are carried out in workshops in Nairobi. Even in Mombasa, the second largest city in the country, it is hard to find a technician specialising in PV. According

to interviewees, this centralisation is due to logistics issues, especially stock management for spare parts, and profitability, for which sufficient business volumes are required.[12]

Figure 1: Value chain of new solar products

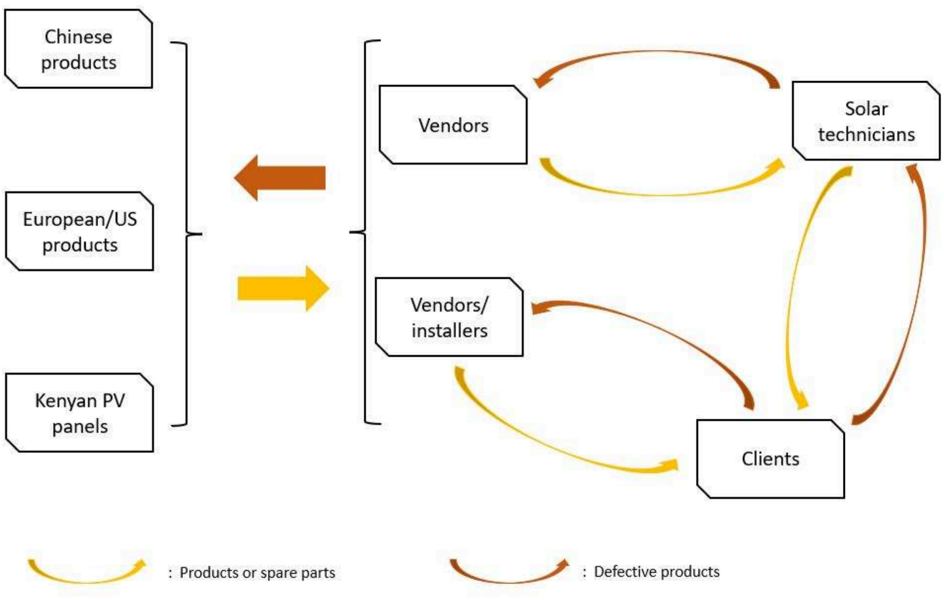


Figure 2: repairs workshop in one of the largest companies in Nairobi (Baraillé, 2020)

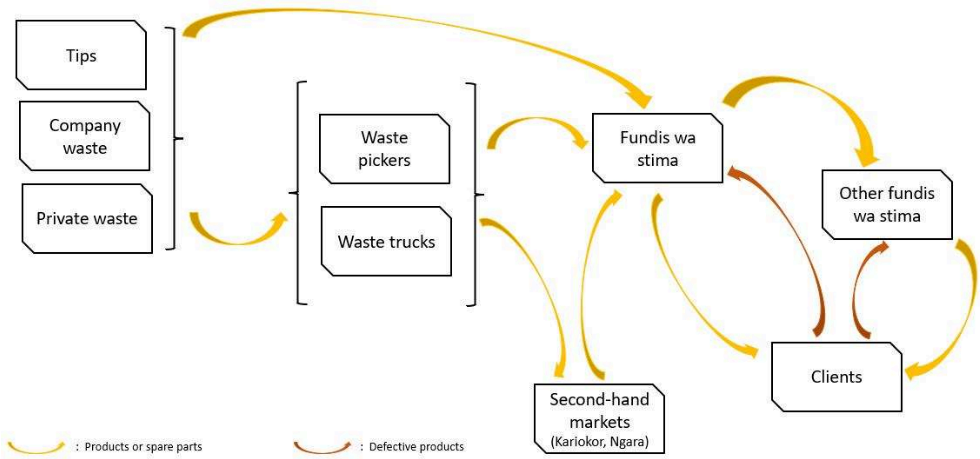
17 We may identify two clearly distinct categories of agents working in repairs. On the one hand, certified distributors and companies from Kenya or abroad. They work on the formal market, selling and installing material by companies specialising in solar. For

repairs, they organise a reverse logistics chain using local outlets for the return of products to the Nairobi workshop which is in contact with manufacturers for spare parts, replacement products, and for returning defective products that cannot be repaired (see figure 1). For the domestic solar kit segment, local outlets often offer to replace irreparable products which they send to the central workshop for reconditioning and then storing as replacement products. For the already electrified segment and for large installations, repairs are organised in a relatively similar manner, but in addition temporary substitute products are systematically provided. Minor repairs can be carried out on site by subcontractors, with equipment being returned to the Nairobi workshop in the event of persistent problems. Under this system based on geographical and functional centralisation, maintenance and repair activities are marginal to the dominant economic model, as illustrated by the small size of repair workshops, including those of the largest players on Kenya’s solar market (see figure 2).

18 On the other hand, self-employed electrical and electronics technicians, called *fundis wa stima* in Kenya, form a *jua kali* micro-industry in *kienyeji* repairs.[13] This informal urban repair economy pre-existed the rise of the solar market, and includes many technical specialities (car and motorised two-wheel vehicle mechanics, household appliances, machine tools, air-conditioning units, etc.), and alters in the light of changing demand. Repairs are carried out in (very) small production units, which are neither incorporated or registered, operating outside regulatory frameworks. They have low internal organisation and are often fairly short-lived. In Nairobi they are grouped in the Ngara recovery district, amounting to an “urban electronic mine” (Reboux, 2018) whose spatial organisation reflects their business specialisation. The dozens of *fundi* stores specialising in recovering, reusing, patching up, and repairing electronic apparatus and household appliances are concentrated around Nyayo Market. The work is divided into separate activities: some sell but do not repair; others disassemble equipment and sell components and spare parts; yet others repair and sell equipment; and a few, lastly, specialise in producing solar equipment, especially inverters (see figure 3). Like many self-employed repairers in developing countries (Balls, 2016), *fundis* are inventive in the way they patch things up, and have “technical confidence” (King, 1996) in their ability to understand and fashion materials and machines. In Ngara, this transpires in the fact that certain *fundis* make their own *jua kali* inverters from components recovered from second-hand UPS (Uninterruptible Power Supply) equipment used to protect computers from power outages. For their solar installations, other *fundis* in Ngara often choose these *jua kali inverters* over those found in stores in the city centre, claiming they are better quality and less prone to overheating. Kenyan consumers thus very frequently turn to the services of a local *fundi*, trusting in his reputation and recommendations from other clients.

Figure 3: A *fundi wa stima* store in Ngara district (Baraillé, 2020)

Figure 4: Value chain for second-hand products (Baraillé, 2020)



19 Ngara's *fundis* obtain equipment and spare parts in extremely varied ways (see figure 4). They may get new equipment from electronics stores in the city centre or major companies in the sector, such as Chloride Exide for batteries, whose products are guaranteed. They buy their second-hand products and spare parts at the *Kariokor* market near Ngara, or from other *fundis* in the district. Trucks transporting second-hand household appliances, and waste pickers carrying sacks of electronic components on their backs, roam around Ngara district selling their merchandise to *fundis*, who may also go directly to private houses, companies, or dumpsites in an informal circular economy of a type that is well documented for African cities (Jaglin *et al*., 2018).

2.2. Recovery and repair technicians largely shut out from the solar market's logistic chains

20 There is some degree of contact between these two main repair segments, in the form of supplies and subcontracting. Nevertheless, companies in the formal market wish to control their products throughout their life-cycle, and are reluctant to turn to local technicians, and, more generally, prefer to replace rather than repair. The integration between the two segments thus varies significantly, with the *fundis* being sidelined from the solar value chain.

21 Subcontracting dominates for the installation of equipment. For the most profitable segments, companies providing installation and maintenance contracts for their industrial and commercial clients generally subcontract installation to EPRA-licenced technicians—EPRA being the body regulating the energy sector in Kenya—who may in turn subcontract to local *fundis*. On BoP markets, companies such as M-KOPA, which operate in regions where there are few EPRA-licensed technicians, and whose solar kits may be installed with little technical skill, often turn directly to *fundis* for installation, viewing them as an interesting way to expand their territorial coverage.

22 Companies are more wary when it comes to repairs, especially of solar kits, and place little faith in *fundis'* skills. Indeed, most *fundis* have picked up what they know about solar and electronics "on the job". Nevertheless, the main criticisms are levelled by companies working on the (mainly rural) electrification market with mobile phone payments based on usage. To protect the PAYGO payment system and patented technologies they use, their solar equipment is designed so that only the manufacturer or authorised distributor can open it, and they can only be repaired using the manufacturer's spare parts. For example, the screw heads are specific to the company, and electronics circuits are covered in a coat of paint to prevent their various components being identified by reference number.[14] In practice, it is virtually impossible for even experienced self-employed technicians to repair domestic circuits without using the product return circuit organised by the companies themselves, a situation which contravenes recommendations on how to make the deployment of pico-PV more sustainable all along the value chain (Hirmer & Cruickshank, 2014).

23 Additionally, on the highly competitive solar market in which technologies change rapidly, companies and approved distributors often identify two types of competition: first, competition on the market for branded products subject to various controls, deemed "loyal"; and second, competition stemming from the flooding in of generic Chinese low-quality products, deemed "unreliable", and thus damaging to people's trust in solar technology.[15] The former thus seek to protect their installations and to control any repairs on their material in order to safeguard their brand and their technology. Products under warranty are thus sealed and may not be opened. Typically, the warranty is for one or two years and covers any defect in the product, but not problems stemming from installation or use, and the manufacturer includes its cost in the price of the product. But such a product warranty model is ill-suited to the context in sub-Saharan Africa and to consumption practices there, and though included in the sale price, the warranty rarely functions in practice, or even not at all (Davies, 2018). This is because clients rarely have proof of date of purchase, resellers do not always have the spare parts, the distance to the vendor discourages consumers from invoking their rights, or else the problem stems from how the product was used and so is not

covered by the warranty. The product warranty does little to protect those buying solar kits, and runs counter to an economical system based on maintaining and repairing equipment.

2.3. More jobs in sales than in repairs

24 In Kenya, most jobs in solar are created in the sale and distribution of equipment. The Powering Jobs Census found that, for the period 2017-2018 in Kenya, the renewables and decentralised energy sector accounted for 25,000 direct jobs, 10,000 of which were in the formal economy—almost the same number as the 11,000 jobs at Kenya Power, the national operator—and 15,000 in the informal sector. Sale and distribution made up 40% of these direct (formal and informal) jobs, with operation and maintenance accounting for only 5%, the same figure as for manufacture and assembly (Power for All, 2019). The remaining direct jobs were in product support (15%), installation and product development (10%), R&D (2.5%), and management and administration (22.5%).

25 Let us start by noting that most electronics stores in the centre of Nairobi care little about the products they sell and know little about solar. They do not conduct maintenance or repair, and only rarely install equipment, for which they direct their clients to *fundis*. In this case, they offer a guarantee and are in contact with the manufacturer or an official distributor to replace defective products under warranty.

26 For the companies dominating Kenya's solar market, particularly the electrification segment, sale is central to their business model based on rolling out new kits. Their main objective is to increase the number of clients to whom they can then propose upgrading their kit, to add a television or fridge for example. Conversely, repair has little place in their business model. It is seen as not very or not at all profitable due to the distribution of low-quality products across vast, sparsely populated territories, and the low production cost of the components used.[16]

27 These economic rationales comply with the expectations of providers of initial capital (venture capital and environmental investment funds) investing in companies operating on emerging markets, often perceived as risky. For example, M-KOPA initially developed thanks to trial-phase investments by the Shell Foundation and the African Enterprise Challenge Fund, before the impact investment firm Grey Ghost Ventures took a stake in the company (Rolffs *et al.*, 2014). The model for rolling out PAYGO solar kits is based on a major initial investment, with revenue from reimbursing the kits spread out over 2 to 3 years. This particularly capital-intensive strategy incites companies to turn to capital providers for initial investment. The objective is thus to subsequently increase the number of units "placed" so as to expand the revenue base as much as possible so as to securitise flows by spreading the risk of non-payment (Lighting Global *et al.*, 2020). Local sales outlets play a key role in this model: their agents must do all they can to place products without wasting any time on repairs, even when a problem has been identified. Defective products may be shipped to Nairobi where a team not in charge of sales will try to repair them.[17]

3. Repair undermined by the revolution in microelectronics and the shift towards fully disposable products

28 The primacy of sales objectives sidelines long-term preoccupations about conserving resources and the functional lifespan of equipment, a trend worsened by the recent rapid development in microelectronics, encouraging replacement rather than repair, even in Nairobi workshops where there are large quantities of waste.[18] The entire repair and recovery micro-industry is threatened by the revolution in microelectronics and by the design of products devised and manufactured outside Kenya.

3.1. Replacing rather than repairing

29 The *fundis* of Ngara distinguish between “original” products, which have long been made by European and Japanese brands, and “Chinese” products which are more recent and of lesser quality. Sellers privilege “Chinese” products as they are cheap, but self-employed repairers prefer the former for they are easier to repair and contain more precious materials for sale on the recycling market, such as the gold on motherboards, for instance.[19] Microelectronics makes it possible to reduce the production costs for circuit boards and to increase energy efficiency, but these new products are hard to repair and manufactured at such low cost that it is no longer profitable to replace them. And so instead of being sent for repair, they go to landfill or,[20] in the best-case scenario, to recycling centres.

30 Solar equipment is affected by the same rationale of low-cost production affecting all electronic products, meaning it tends to be systematically replaced rather than repaired. This is compounded by the pace of technological change, meaning equipment becomes obsolescent more rapidly: spare parts disappear from the market, and demand drops for products viewed as “out of date”. Rather than trying to get a component to work again, typically the inverter controller card, repairs mainly consist in replacing it. This is further amplified by the influx of cheap Chinese products in direct competition with second-hand products repaired and sold by local repairers.

31 In addition to engendering large quantities of waste, this shift in practices is based on the long-distance supply of spare parts from abroad, taking a few weeks by boat or a few days by plane. Manufacturers often provide distributors with spare parts or replacement products when they place orders (around 3% of the volume order) to cover the replacement of products under warranty. But businesses in Kenya generally hold limited stock due to rapid technological change and obsolescence. Under these circumstances, the volume of repairs in Nairobi is limited, especially for solar kits.[21] Although large companies have small teams dedicated to repairs—to honour their warranty, even though this activity is not profitable—, independent technicians struggle to rent or buy a dedicated repair workshop given the rise of fully disposable products, limiting the prospects for such a business: “Now, you see why I don’t have a workshop”.[22]

32 *Kienyeji* repairs, based on Ngara’s *fundis* salvaging and reassembling products, have thus progressively been sidelined from the market. It should be emphasised that this change coincides with the consumption practices of the African working classes which, to

purchase new material goods, are compelled to buy “disposable” cheap BoP products (Jaglin, 2019). “Green” energies are thus actively involved in a new “extractivism”, thereby compounding the emerging problem of solar waste (Cross, 2019).

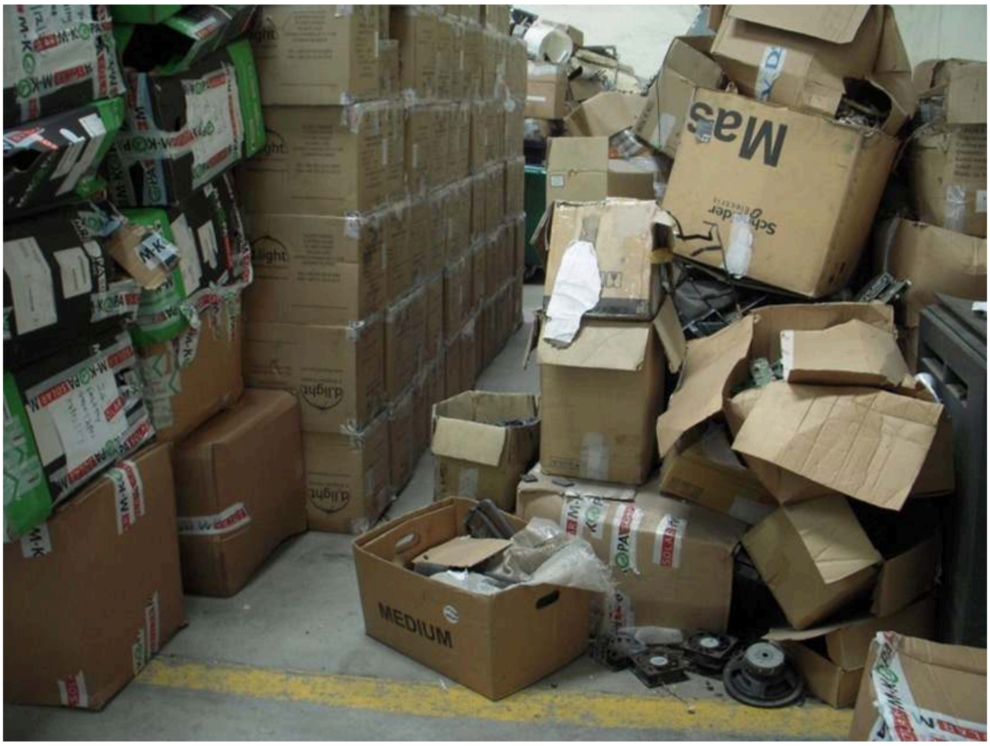
3.2. The solar market and its waste: a diffuse chain of responsibility

33 Although well-known to various stakeholders, the environmental problem caused by solar market waste (Bensch *et al.*, 2017) tends not to be fully taken into account. Companies working in the already electrified segment generally carry out medium or large installations using good-quality products with a relatively long lifespan (about 25 years for solar panels and 10 years for batteries). Waste management is thus still very much a coming problem for these companies. Conversely, for those operating in the solar kit electrification segment, where the lifespan of the products is more limited, waste management is an especially pressing problem given that many perceive themselves as environmental businesses: “A lot of the solar business is classified as social enterprises, and seen as doing the right thing environmentally, replacing kerosene and its effect on people’s health and the environment. We are clean energy companies and we want to promote the right thing for our customers and for the environment which we operate in. So, the fact that we are selling products that have batteries and stuff like that means that we also want to manage that responsibly towards end-of-life.”[23] End-of-life batteries and other materials, scattered around vast rural areas without any adapted recovery facilities, are a major source of pollution (Bensch *et al.*, 2017; Lighting Global *et al.*, 2020; Ondrazcek, 2013). Several solutions have been trialled in response to this.

34 Certain relate to collecting products. Companies have thus developed pilot schemes to encourage users to return their out-of-order domestic solar kits, offering them a savings voucher on new equipment, for example. Nevertheless, this approach has run into several problems. First, only a tiny proportion of solar kits are in fact collected and recycled, since out-of-warranty products are excluded. Second, the cost of systematically collecting and processing them needs to be integrated into the sales price of domestic solar kits, on an extremely price sensitive BoP market.

35 Others schemes relate to processing end-of-life products. Some companies organise the processing of returned products under their product warranty, while others take the opportunity to recycle their waste stocks. This is especially the case of a program run by Sofies, a sustainability consultancy, and the CDC Group, the financial arm of UK Aid, which subsidises solar waste processing and various schemes to encourage users to return defective products. Several companies have disposed of all their waste stocks.[24] Let us here mention the case of companies selling domestic solar kits which are confronted with rapid product changes and markets sensitive to reputation. To win or retain their clients’ trust, they refuse to allow their brand to be associated with any second-hand products, which might be defective or may have been tampered with, and so, to protect their technology, rapidly withdraw new goods from the market once they are deemed obsolete. Rather than being repaired or reconditioned, all these goods are disposed of and partly recycled (see figure 5), thus contributing to waste production.

Figure 5: Stocks of obsolete products in an e- waste processing plant in Nairobi (Baraillé, 2020)



36 In general, only recyclable waste is collected and processed. Although processes are being developed, there are no local solutions for recycling lithium batteries which are extensively used by companies in the sector, and as things stand only the glass panel on solar panels are fully recycled, the rest going to landfill. Under these circumstances, recycling rather than reusing products is problematic, as emphasised by Cross and Murray (2018). Nevertheless, while Kenya and other African countries have a sizeable reuse market, especially for household appliances, it is not certain, in the current state of knowledge, that any such market exists for solar, for which it is mainly inverters that tend to be recovered (for instance, to reassemble the controller integrated circuit board with UPS components). The decisions made by the Kenyan solar industry to bring affordable individual equipment to market not only destabilise the local maintenance and repair economy, but also, with the generalisation of disposable products, engender an environmental problem that waste management is unable to resolve.

Conclusion: the limits to the environmental and social sustainability of Kenya's solar market

37 With the backing of international organisations, Kenya has decided to rapidly develop a solar electricity market, especially via the rollout of individual domestic kits. This strategy is often presented as a success (Byrne *et. al.*, 2018). Indeed, it is a successful example of constructing a mass market,[25] with strong public support and steady backing by international donors who, in exchange for sectorial reforms, have made it easier to raise capital for the energy sector (Newell & Phillips, 2016). Donors have thus played a crucial role in putting together pilot projects, organising tests for the various business models, providing guarantees to companies and investors, and more generally protecting a niche from which the PAYGO innovation was able to develop (Rolffs *et al.*,

2014). The domestic solar market stemmed less from heroic private entrepreneurs than from a "political economy of niche-building" (Byrne *et. al.*, 2018). There is broad consensus among donors, businesses, and Kenya's state elites about this strategy to rely on private agents to supply essential public goods within the framework of market discipline (*idem*). It nevertheless raises questions, particularly about the stated social and environmental objectives.

38 This article has looked at maintenance and repair activities to examine the effects this electricity policy has on the changes in a sector generally viewed as creating local jobs, and with the potential to make a major environmental contribution as part of an energy-efficient circular economy reducing ultimate waste flows through recycling and reuse. As we have seen, given current choices, Kenya's strategy to develop a dynamic solar market has had little effect on repair activities. First, because the oligopolistic organisation of repair activities as organised by dominant businesses sidelines the *fundis* and their pre-existing urban economy of repair and recycling. Second, because repair holds a marginal place in these companies' business models, hindering innovation and efforts in this field. Lastly, maintenance and repair services and know-how are under general threat and being rendered obsolete by the growing integration of disposable microelectronic components in solar equipment.

39 These observations reflect the strong asymmetries in relations between those involved in the solar industry in Kenya, the dynamics at work in the globalised solar and micro-electronics industry, and national policy choices. The neoliberal vision guiding the development of a solar electricity market encourages businesses and approved distributors whose main strategy is to sell new equipment. On the domestic solar kit segment, the need for affordable products for bottom-of-the-pyramid customers works in favour of imported Asian products, which are cheaper than those manufactured locally (Lam *et al.*, 2018), but are of poor quality and difficult to repair. It is thus not in the interest of these businesses to promote the reuse of products and recovery of waste: the PAYGO model enables them to sell new equipment, of a quality that militates against repair.

40 In the light of these findings, Kenya's solar policy seems to conform only very partially to its stated social and environmental objectives. Although it helps decarbonise the industry, it is nevertheless subject to the dynamics of a "new" globalised extractivist economy and engenders the local production of large and growing quantities of waste, causing an environmental problem that is widely overlooked. Presented as driven by "philantrocapitalism" (Cross, 2019) and as contributing to the emergence of a new re-localised green economy, Kenya's solar market, especially in domestic solar kits, illustrates the complexity of the energy transition in sub-Saharan Africa, throwing light on the largely irreconcilable objectives of a business-driven individual electrification policy.

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NOTES

1. “Electric Hybrids: emerging forms of energy transition in southern cities”: research financed by the ANR (2018-2021) and coordinated by Eric Verdeil and Sylvy Jaglin. https://hybridelec.hypotheses.org/

2. Pico-solar equipment produces 10Wp or less (Lighting Global *et al.*, 2020).

3. US Energy Information Administration, https://www.eia.gov/international/data/world/electricity/electricity-capacity?pd=2&p=0000000000000000000000007vo7&u=0&f=A&v=mapbubble&a=-&i=none&vo=value&t=C&g=none&l=249--117&s=315532800000&e=1514764800000&, accessed 14/08/2020.

4. World Bank, https://donnees.banquemondiale.org/indicator/EG.ELC.ACCS.RU.ZS?locations=KE, accessed 14/08/2020.

5. World Bank. “System Average Interruption Duration Index (SAIDI)” and “System Average Frequency Duration Index (SAIFI)”, https://databank.worldbank.org/reports.aspx?source=3001&series=IC.ELC.SAID.XD.DB1619, accessed 14/08/2020.

6. Ministry of Energy and Petroleum. “Last Mile Project”, https://energy.go.ke/?p=914, accessed 22/04/2020.

7. Ministry of Energy and Petroleum. “About KOSAP”, https://energy.go.ke/?page_id=7185, accessed 22/04/2020.

8. But compliance tests are carried out prior to import, making it difficult to effectively control imitations (interview, KEBS, 6 February 2020).

9. Under the PAYGO model, solar equipment is bought in daily instalments of around KES50 (about €0.50), meaning much of the rural population can afford domestic solar kits.

On 30 September 2020, the European Commission's exchange rate stood at €1 for KES128, https://ec.europa.eu/info/funding-tenders/how-eu-funding-works/information-contractors-and-beneficiaries/exchange-rate-inforeuro_en, accessed 30/09/2020.

Davis & Shirtliff Chloride Exide catalogues, two of the main solar equipment distributors in Kenya, https://www.davisandshirtliff.com/shop/solar and https://www.chlorideexide.com/solar/?sels=swh, accessed 14/08/2020.

10. An inverter converts the direct current produced by solar panels into alternating current (the type used by the grid), for which most electrical equipment is designed. Some equipment can function using direct current, but it is rarer and more expensive.

11. Interview with company 1, 9 January 2020; interview with company 7, 3 February 2020.

12. interview with company 3, 24 January 2020; interview with *fundi* 8, 12 February 2020.

13. *Jua kali*, meaning "burning sun" in Kiswahili, is used to designate the local micro-industry and its products, while *kienyeji* means local.

14. Interview with *fundi* 1, 1 February 2020; interview with *fundi* 8, 12 February 2020.

15. Interview with company 1, 9 January 2020.

16. Interview with company 3, 24 January 2020; interview with *fundi* 8, 12 February 2020.

17. Interview with company 3, 24 January 2020; interview with company 4, 5 February 2020.

18. Out of the 57,000 tons of electronic waste generated in Kenya in 2017, 1,500 tons came from off-grid solar products, amounting to about 3% of the country's total e-waste. Projections estimate that the quantity of waste stemming from off-grid solar products will steadily increase, to reach about 5,000 tons in 2022 (Magalini *et al.*, 2017).

19. Interview with *fundi* 2, 4 February 2020.

20. Interview with *fundi* 8, 12 February 2020.

21. The average percentage of off-grid solar products returned during the warranty period is about 7%. This figure does not correspond exactly to the volume of repairs, for many of these products are directly replaced. In Kenya, for the period 2014-2017, 530,000 defective products were thus returned to the main companies working in the sector, which rolled out over 8 million products during the same period (Magalini *et al.*, 2017).

22. Interview with *fundi* 8, 12 February 2020.

23. Interview with company 6, 28 January 2020.

24. Interview with company 7, 3 February 2020.

25. Domestic solar kits are intended primarily for the "rural middle classes", representing between 55% and 65% of rural off-grid households in Kenya, a relatively high proportion in comparison to other countries in sub-Saharan Africa (Rolffs *et al.*, 2014).

ABSTRACTS

In Kenya and sub-Saharan Africa more broadly, decentralised solar electrification solutions hold out the promise of local development that both respects the environment and creates jobs. By examining the maintenance, repair, and recycling of photovoltaic solar equipment, this article compares these hopes to the actual impact of Kenya's solar policy on changes in a sector generally considered to provide local jobs, and with the potential to make a major environmental contribution to a resource-efficient circular economy conducive to recycling and reuse. It starts by showing that Kenya's strategy of developing a dynamic solar market has had little impact on repair activities. First, because the industry's dominant companies bypass the *fundis* (as technicians working in the pre-existing urban repair and recycling economy are called). And second, because repair is marginal to these companies' business models. It then argues that repair services and know-how are being rendered obsolete by the increasing number of disposable microelectronic components in solar equipment, and looks at the environmental consequences of an industry producing increasing quantities of waste that is unsatisfactorily managed. In the light of these observations, it finally discusses the ambiguities of an electricity policy presented as conducive to a new relocalised green economy.

Les solutions d’électrification solaire décentralisées portent l’espoir, au Kenya comme plus largement en Afrique subsaharienne, d’un développement local respectueux de l’environnement et créateur d’emplois. En s’intéressant aux activités de maintenance, de réparation et de recyclage des équipements solaires photovoltaïques, l’article confronte ces attentes aux effets de la politique solaire kenyane sur l’évolution d’un secteur généralement considéré comme pourvoyeur d’emplois locaux et dont la contribution environnementale à une économie circulaire sobre en ressources, propice au recyclage et au réemploi, est potentiellement importante. Il montre d’abord que la stratégie kenyane de développement d’un marché solaire dynamique a peu d’effets sur les activités de réparation: d’une part, les *fundis*, artisans d’une économie urbaine du dépannage et du recyclage préexistante sont contournés par les entreprises dominantes du secteur; d’autre part, la réparation occupe une place marginale dans les modèles d’affaires de ces entreprises. Il souligne ensuite que les services et savoir-faire de la réparation sont progressivement rendu caducs par l’intégration croissante de composants micro-électroniques jetables dans les équipements solaires, et interroge les conséquences environnementales d’une industrie productrice de quantités croissantes de déchets dans un contexte où leur gestion reste problématique. Au regard de ces constats, il discute enfin les ambiguïtés d’une politique électrique présentée comme favorable à l’émergence d’une nouvelle économie verte relocalisée.

INDEX

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