Study on feasibility of the ProBaMet approach in other countries and secondary non-ferrous metals supply chains

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List of Abbreviations

EPR	Extended Producer Responsibility
HICs	High-income countries
HSE	Health, safety, environment
LAB	Lead-acid battery
LCO	Lithium cobalt oxide
LFP	Lithium iron phosphate
LMICs	Low- and middle-income countries
µg/dl	Microgram of lead per decilitre of blood
NEMC	National Environment Management Council (Tanzania)
PCB	Polychlorinated biphenyl
POPs	Persistent Organic Pollutants
PPE	Personal Protective Equipment
ProBaMet	Partnership for Responsible Battery and Metal Recycling
PV	Photovoltaic
PWB	Printed Wiring Board
SOPs	Standard Operating Procedures
t/a	Metric tonnes per annum
ULAB	Use lead-acid battery
UN	United Nations
UNEA	United Nations Environment Assembly

1 Background & introduction

The Partnership for Responsible Battery and Metal Recycling (ProBaMet) project was launched in early 2024 with the aim to stimulate and realise systematic improvements in the recycling sector for used lead-acid batteries (ULABs) in Nigeria. The project is implemented by Oeko-Institut, Sustainable Research and Action for Environmental Development (SRADev Nigeria), Plattform Blei (Platform Lead of the Wirtschaftsvereinigung Metalle), and the Alliance for Rural Electrification (ARE). It is funded by the Federal Ministry for Economic Cooperation and Development (BMZ) and supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

The lead-acid battery recycling sector and Nigeria have been chosen because of their relevance in terms of secondary raw materials, the sectors' size, as well as the known environmental and human health problems: Nigeria is Africa's largest economy and hosts a large lead-acid battery recycling industry with around ten industrial facilities being active in this field. Pollution scandals and research revealed systematic shortcomings of this industry in Nigeria with severe adverse effects on human health and the environment (Gottesfeld et al. 2018; Anyaogu 2018a, 2018b; Anyaogu et al. 2018; Ugbor 2016). At the same time, used lead-acid batteries are a major source of important secondary raw materials, namely lead, tin and antimony. International manufacturing industries have a high demand for these raw materials, and African economies (particularly larger and more developed countries and markets such as Nigeria) increasingly move into the focus for sourcing such recycled metals.

In that context, more and more mandatory and voluntary sourcing policies come into play where buyers and users of raw materials are required to conduct thorough supply chain due diligence, including risk assessments and – in case risks have been identified – effective mitigation measures. Due to the hazardous nature of lead and used lead-acid batteries (ULABs), sourcing of such secondary raw materials from low- and middle-income countries is subject to various supply chain due diligence risks, most notably emissions of hazardous lead and related exposure of workers and neighbouring communities. Considering the manifold evidence for misconduct in many plants operating in low- and middle-income countries, it becomes obvious that **this secondary raw material streams requires attention from various sides:**

1. **Governments and regulatory agencies** in affected countries must prioritise this sector and mandate and enforce effective sector standards that limit (and, if possible, eliminate) the scope for unsound management and recycling within the respective country. The UNEA resolution on "Eliminating exposure to lead paint and promoting environmentally sound management of waste lead-acid batteries" underlines this necessary government prioritisation (UNEA 2017).

2. **Players using and controlling batteries in a country** are called to review disposal habits of used batteries and aim at systems where batteries are channelled away from unsound management and towards best performing players in a country or region. Related approaches have overlaps with the concept of Extended Producer Responsibility (EPR) and have been codified in various jurisdiction.

3. **Buyers and users of secondary raw materials** must conduct supply-chain due diligence and ensure that their purchasing decisions contribute towards sector improvements.

Last but not least, the recyclers operating in Nigeria must improve their operations to meet minimum standards and should follow a constant improvement approach. Due to the competitive nature of the sector, these efforts must be stimulated and supported by the measures above[1]

[1] In effectively unregulated markets, facilities with high standards are generally unable to compete with facilities with lower standards. Although facilities with high standards may in some respects have higher lead recovery rates, the additional investment and operational costs exceed the additional revenues from the sale of raw materials. Therefore, improvements in this sector cannot be based solely on voluntary improvements by individual plants but must take into account the levers listed under 1-3 above.

The ProBaMet project combines these angles above and classifies them into ‘push-‘ and ‘pull factors’, with push factors summarising all regulatory attempts around setting and enforcing minimum standards (No 1 above), and pull factors summarising the growing mandatory and voluntary market demands for sound battery disposal and responsibly sourced secondary raw materials (No 2 and 3 above).

Since project start, various steps have been undertaken to improve the sector in Nigeria, and it is envisaged that – in the medium term, the Nigerian ULAB recycling sector will be characterised by the **following changes:**

- Well-established **minimum standard** that is regularly monitored and enforced by the responsible agencies;
- **Commitment of recycling plants** to these minimum standards, as well as to continuous improvement;
- **Identification and public promotion of best performing ULAB recycling plant(s)** operating in Nigeria;
- **Monitoring of lead exposure** on the level of workers;
- **Increased awareness and efforts by battery-using and -controlling sectors in Nigeria** to channel ULABs to the recycler(s) identified as the best performing ones;
- **Sourcing policy of major buyers** of secondary lead from Nigeria that strengthens minimum standards and best performing recycler(s) in Nigeria.

While the concept was developed and applied for ULAB recycling in Nigeria and is being applied in a similar manner in Ghana[2], its applicability to other recycling sectors, countries and regions has not yet been tested. In the context of a globally increasing demand for secondary raw materials, as well as an increasing awareness of sustainability risks associated with raw materials and recycling processes, this paper aims to explore the feasibility of applying the ProBaMet approach to other countries and secondary raw material streams. **In specific, the paper assesses:**

- **The feasibility** of applying the ProBaMet approach to ULAB recycling sectors of **other countries and regions;**
- **The feasibility** of applying the ProBaMet approach to **other secondary non-ferrous metals** such as aluminium, zinc and others.

The analysis presented is based on literature review, existing project and industry expertise in the related secondary waste and material streams, and interactions with key stakeholders in ProBaMet as well as the non-ferrous metals industry.

2 The ProBaMet approach

The ProBaMet approach was developed to stimulate systematic changes in geographical areas where recycling of used lead-acid batteries (ULABs) often follows sub-standard and highly polluting patterns. While the approach is based on broad multi-stakeholder participation, bringing together government actors, civil society, academia, and the private sector to join forces for targeted improvements in the sector, its key feature is the combination of push factors (regulation & enforcement) with pull factors (market demand for sound recycling solutions and the raw materials they produce). Due to the competitive nature of the ULAB recycling sector, the approach requires a national approach. This means that it must be applied to all industrial ULAB recyclers in a country. Focusing exclusively on one or a few plants, while leaving others unaffected (particularly with regard to enforcing standards), not only jeopardises the effectiveness

[2] In Ghana, sector improvements are supported by the Swiss funded Sustainable Recycling Industries project (SRI), which also supported the development of SOPs and conducted training and joint plant assessments with regulatory agencies.

of the approach, but can also lead to unintended consequences, such as increasing the market share of sub-standard recyclers.

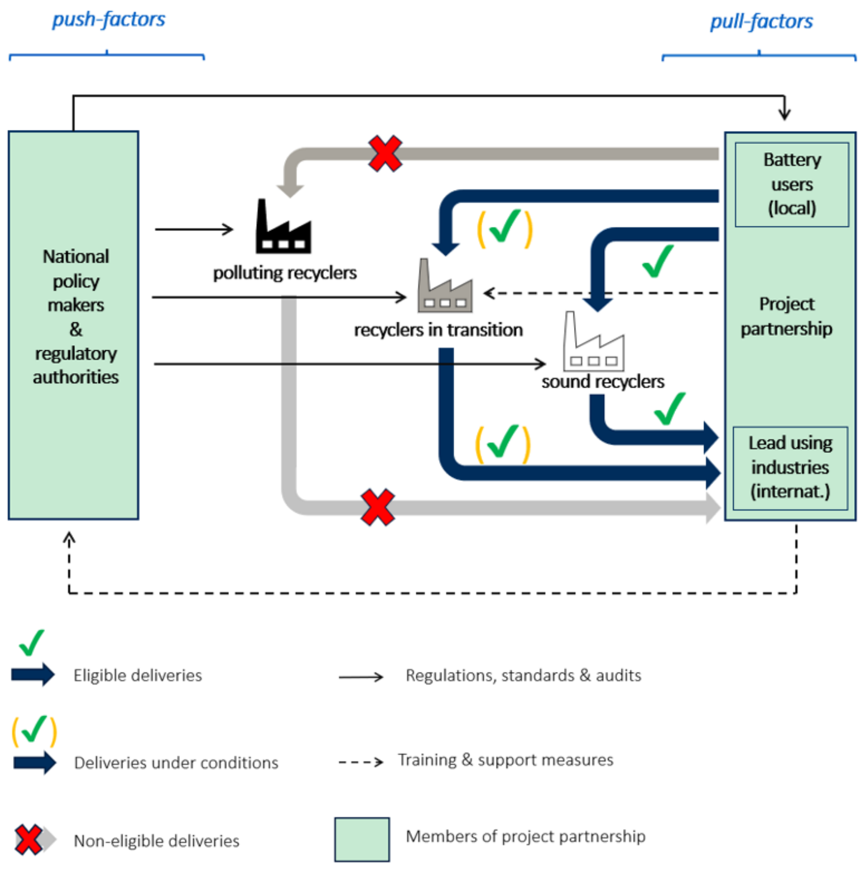
In addition, the ProBaMet approach strongly builds on the following success factors:

- **Existing national awareness:** Key stakeholders in government, civil society and industry must be aware of negative impacts from sub-standard recycling activities and have the willingness for systematic sector improvements in their respective country;
- **Use of a common reference benchmark:** A documented reference benchmark should clearly define sound practices and be acknowledged by regulators, recyclers, as well as players interested in sound battery disposal solutions or the purchasing of secondary raw materials. In the case of lead-acid battery recycling, these are the Standard Operating Procedures for Environmentally Sound Management of Used Lead-acid Batteries (Wilson and Manhart 2021);
- **Strong position of the formal sector:** The recycling sector in focus should be characterised by formal sector players that have a competitive edge over informal operations. While informal sector activities (e.g. in the area of collection) are common in most secondary raw material streams in LMICs, it is important that key processes such as smelting and refining are conducted by entities that require licensing from national authorities and that cannot escape regulatory pressure by frequently relocating their operations.
- **Interest in upstream and/or downstream industries for substantial improvements:** There must be an interest of upstream players (players generating and disposing the relevant waste types) and/or downstream players (players that have interests in sourcing the generated secondary raw materials) to support positive developments in the sector. This interest is needed to develop the intended pull factors.

Figure 2-1 provides a graphical illustration of the ProBaMet concept, which involves a coalition of national policymakers and regulators, battery using sectors[3], as well as lead using industries. By applying a common standard and transformation process, they have the opportunity to significantly influence the national recycling landscape with a view to eliminate the worst polluters and promote the best performers. Recyclers in transition are given the chance to improve their operations, provided they are willing and capable to do so.

[3] In that context, it must be noted that the focus on battery-using sectors is exclusively centred on management solutions within a country and is by no means intended to encourage or support transboundary shipment of hazardous battery waste for the purpose of recycling in Nigeria or any other low- or middle-income country.

Figure 2-1: Overview of the ProBaMet approach



Source: Oeko-Institut

In this way, companies and players that either need an environmentally sound disposal solution for waste batteries or secondary raw materials (mostly lead, tin and antimony) for their business operations can integrate and use this approach to strengthen responsible business conduct with downstream partners (battery disposal) and/or upstream partners (suppliers of secondary raw materials)[4].

3 Applicability to other countries & regions

The ProBaMet approach for lead-acid battery management can be applied in countries that meet the **following criteria**:

1. **Existing health, safety and environmental (HSE) challenges** associated with the unsound recycling of lead-acid batteries;
2. **Existing or developing industrial ULAB recycling infrastructure** (formal sector);
3. **Existing awareness among policymakers and regulators** and willingness for a cooperative sector approach.

The criteria above are explained in more details in the following sub-sections.

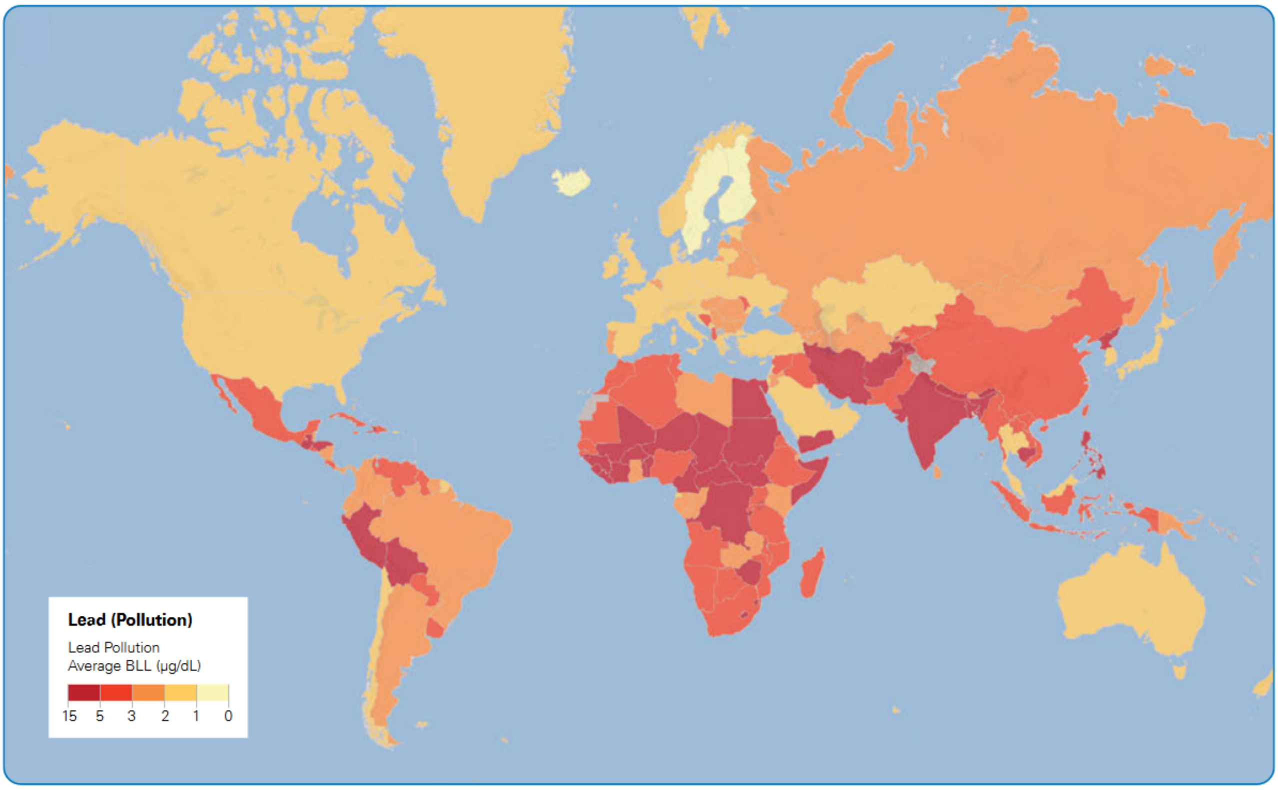
[4] In that context it must be noted that the focus on downstream solutions (sound recycling of old batteries) is exclusively centred at management solutions within a country and is by no means intended to encourage or support transboundary shipment of hazardous battery waste for the purpose of recycling in Nigeria or any other low- or middle-income country.

3.1 Countries with existing HSE challenges in ULAB recycling

Figure 3-1 provides an overview of the average blood lead levels of children in countries around the world. Although there are significant differences between countries, it is noteworthy that higher levels prevail in low- and middle-income countries, particularly in Africa, Asia, and Latin-America (with additional hot spots in Bosnia, Albania, and Moldavia in Europe). While blood lead levels are an excellent indicator for identifying systematic lead exposure, there are several exposure pathways of which ULAB recycling is only one. Other pathways include the use of lead in paints, pottery, cookware, and spices, and heavy metal contamination from other (current and past) industrial activities such as mining and ore processing.

However, Figure 3-1 also highlights countries with significant weaknesses in exposure control, which likely indicates numerous shortcomings, including in ULAB management. The map also broadly aligns with recent reports on sub-standard ULAB management, including cases in Senegal, Nigeria, Ghana; Kenya, Cameroon, India and Bangladesh (Kenyan Ministry of Health 2015; Manhart et al. 2016b; Atiemo et al. 2016; Upadhyay 2022). While the map can serve as an indicative orientation and suggest that problems related to unsound ULAB management may be more prevalent in LMICs than in HICs, but shades of colour between certain countries should not be over-interpreted, exemplified by proven cases of pollution in Kenya, while the country has a relatively low average blood lead level compared to most other African countries.

Figure 3-1: Average blood lead levels in children on a country level



Source: UNICEF & PureEarth (2020)

3.2 Countries with existing or developing industrial ULAB recycling infrastructure

Private investments in industrial ULAB recycling infrastructure are typically made in environments that:

- **Provide access to sufficient numbers of waste batteries** for recycling (typically more than 20,000 t/a and plant);
- **provide political stability** / absence of severe forms of insecurity;
- either have **strong domestic demand for lead** and lead alloys (mostly battery productions) **or have a transport infrastructure to ship lead** and lead-alloys to other markets (road and port infrastructure).

The criteria above apply to a large number of LMICs, with the exception of very small countries, war-affected regions and landlocked countries with weak transport infrastructure.

3.3 Countries with existing government awareness & cooperation willingness

The UNEA resolution on "Eliminating exposure to lead paint and promoting environmentally sound management of waste lead-acid batteries" (UNEA 2017), as well as treatment of the issue in various international forums has helped to raise awareness of the problem of unsound ULAB recycling and the need for the sector to be thoroughly monitored and improved, particularly in LMICs. But the level of awareness levels varies greatly in different jurisdictions. In that context, it is observed that awareness is highest in countries that have already experienced lead pollution scandals resulting from ULAB recycling, which have been reported in the national media or have been the subject of legal or political debate. While there is no global overview of such situations, the following list sketches a rough picture of such incidents on the African continent in recent years:

- **Senegal:** In 2007 and 2008, a settlement near the capital Dakar was affected by a mass poisoning incident due to lead caused by Informal ULAB recycling. At least 18 children under the age of five died as a result (Haefliger et al. 2009).
- **Ghana:** Blood lead tests on workers in a formal recycling facility revealed lead-in-blood levels of up to 278 µg/dl[5] (Atiemo et al. 2016). Another ULAB recycling plant was located next to other industries where workers fell sick due to acute lead poisoning caused by inadequate emission controls at the ULAB recycling plant. As a consequence, environmental authorities prioritized this sector and, supported by the Swiss-funded Sustainable Recycling Industries project, carried out systematic assessments of ULAB recycling facilities, developed Standard Operating Procedures and drew up improvement plans for industrial ULAB recycling plants (SRI 2022). Among other things, two plants that failed to comply with prescribed improvement plans where temporarily closed by the authorities in August 2023 (Carlos Atsu Calony 2023).
- **Nigeria:** Soil sampling and lead-in-blood tests showed that several ULAB recycling facilities were operating well below the required standards in 2018. Amongst other things, it was demonstrated that all children at a school (located near an industrial ULAB recycling facility) had elevated blood lead levels. The findings were reported in various press articles in Nigeria and Germany (Anyaogu 2018a, 2018b; Anyaogu et al. 2018; Gottesfeld et al. 2018). As a result, the issue of lead-acid battery recycling has been prioritized by the environmental authorities with various policy steps and initiatives. Among other things, a National Environmental Battery Control Regulation has been developed and was adopted in 2024. Furthermore, national and regional authorities are actively cooperating in the ongoing ProBaMet project.

[5] Values of 5 µg/dl and beyond are considered elevated levels. In ULAB recycling facilities, 20 µg/dl is considered an alert level and 30 µg/dl is considered a limit value beyond which action must be taken to protect the person(s) from further exposure (Wilson and Manhart 2021).

- **Kenya:** A community living near a ULAB recycling facility repeatedly complained and protested against emissions and contamination from the plant. Various health effects were reported, including miscarriages and deaths. The civic action was spearheaded by Phyllis Omido, a former employee of the plant who was later honoured with various environmental awards for her activism. The plant was finally closed down and the case went to court, where the plant management and government authorities were ordered to pay US$ 12 million in compensation to the affected community (Kenyan Ministry of Health 2015; Christabel Ligami 2020).

- **Republic of Congo:** Recent evidence and press coverage point to highly polluting industrial ULAB recycling operations in the port city of Point Noire (Will Fitzgibbon 2023). As a result, a court ordered the temporary closure of the facility in early 2024 (Will Fitzgibbon 2024).

- **Cameroon:** Various research activities and press reports suggest that industrial ULAB recycling operations in the port city of Duala are highly polluting (Manhart et al. 2016a; Gottesfeld et al. 2018; Will Fitzgibbon 2023).

In addition to the cases mentioned above, there have been and continue to be initiatives and activities in a number of other African countries that prove increased interest from selected stakeholders. These include the following:

- **Burkina Faso:** The government of Burkina Faso was instrumental in initiating the UNEA Resolution on "Eliminating exposure to lead paint and promoting environmentally sound management of waste lead-acid batteries" (UNEA 2017).

- **Ethiopia:** The government of Ethiopia has initiated various consultations to improve the management of waste batteries. This has led, among other things, to the introduction of a series of mandatory technical guidelines for economic operators involved in the life cycle of lead-acid batteries (FDRE Environmental Protection Authority 2023).

- **Tanzania:** In Tanzania, the issue of ULAB recycling was addressed in a project by UNEP and PureEarth, which made policy recommendations to adequately address unsound ULAB recycling (UNEP & PureEarth 2022). In the second half of 2024, the competent regulatory authority National Environment Management Council (NEMC) also committed to a project entitled "Upscaling Sector-improvement of Used Lead Acid Battery Recycling in Tanzania – Improving industrial lead acid battery recycling in Tanzania" in cooperation with Agenda-Tanzania and Oeko-Institut, which was funded by GIZ.

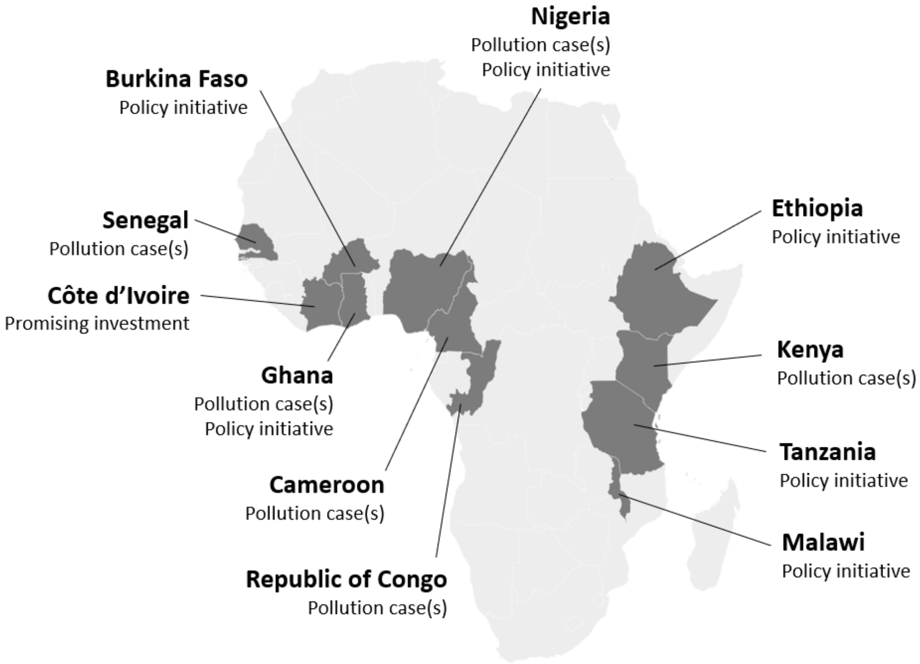
- **Cote d'Ivoire:** An investor has recently installed a ULAB recycling plant with modern technology – probably with the aim of conducting sound recycling operations (Andrew Draper 2024). Such investments may reflect either a heightened awareness on the part of the government or reflect a business approach to more responsible recycling. Partners from the renewable energy industry indicated a high demand for verified, sound ULAB recycling/disposal options in Cote d'Ivoire[6].

- **Malawi:** The country is a founding member of the Partnership for a Lead-Free Future and the president (Mr. Lazarus McCarthy Chakwera) was a speaker at the founding ceremony at the 79th session of the UN General Assembly in September 2024.

Figure 3-2 provides a geographical overview of the countries where unsound ULAB recycling is already the subject of political initiatives and/or increased awareness among relevant stakeholders. This analysis may not be complete, and it cannot be ruled out that there is similar awareness and/or initiatives in additional African jurisdictions not listed in Figure 3-2.

[6] Similar needs have been expressed for Benin and Madagascar.

Figure 3-2: African countries with heightened awareness for lead-acid battery recycling industry risks



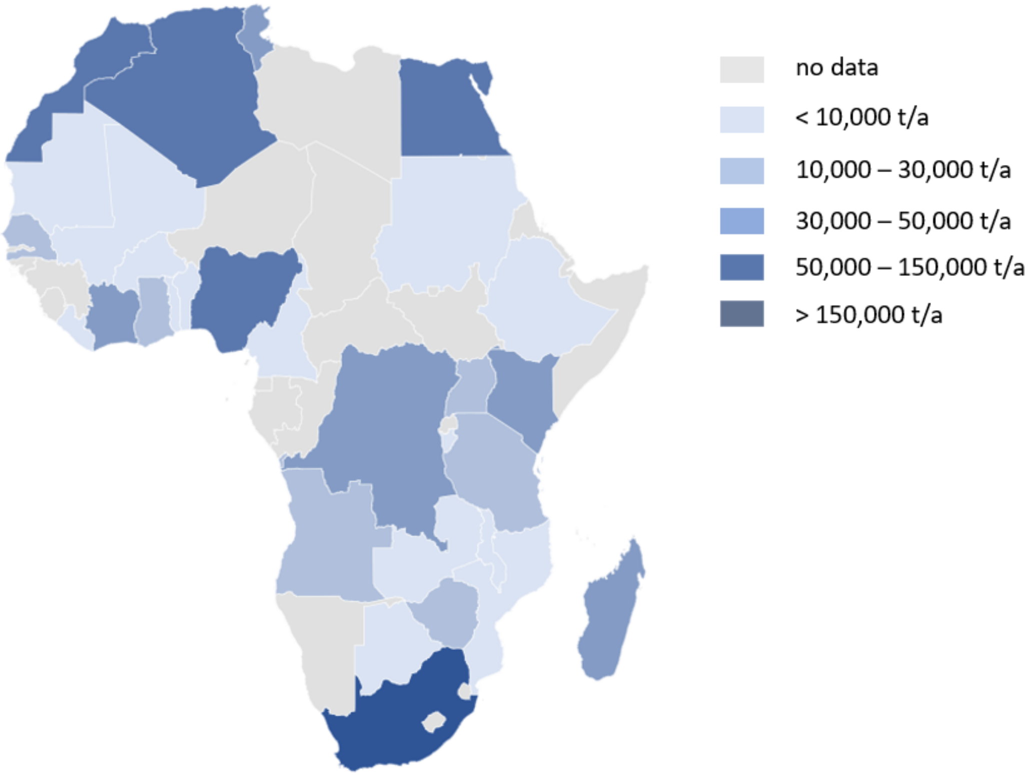
Source: Authors' own illustration

3.4 Countries with large end-of-life battery volumes

The amount of ULABs are another important parameter for the applicability of the ProBaMet concept: While total amounts of waste batteries of less than 10,000 t/a argue against the feasibility of local industrial recycling, larger volumes are usually an important factor for investors to set up recycling plants, provided that other business factors also support this decision. Figure 3-3 shows the estimated quantities of ULABs generated in 2016 in various African countries through use in vehicles (Tür et al. 2016). While the map provides an overview of countries that stand out in terms of ULAB generation (S-Africa, Algeria, Egypt, Morocco), the data does not provide a complete picture due to the following aspects:

- The figure is based on vehicle use in 2016. In most countries, the motorisation rate increased since that time.
- LABs are also used in various other applications, such as back-up power systems and decentralised (solar) electricity supply. In both sectors, there is a disproportionate demand in many African countries.

Figure 3-3: Estimated ULAB generation from use in vehicles in 2016



Source: Tür et al. (2016)

It can be concluded that, in addition to South Africa, Algeria, Egypt and Morocco, a number of other African countries have significant annual ULAB volumes. These include Côte d'Ivoire, Madagascar, Tunisia, Kenya, DR Congo, Angola, Ghana, Senegal, Tanzania, Uganda and Zimbabwe, but other countries could also be relevant.

Battery volumes are certainly also high in various other low- and middle-income countries in Asia and Latin-America. In terms of pull factors as described in chapter 2, trade routes and geographical proximity also influence the feasibility of the ProBaMet approach. From a European perspective, African countries (particularly along the north and west coast) can be considered quite close.

3.5 Interim conclusion

4 Applicability to other secondary raw material streams

As explained in chapter 2, the ProBaMet approach requires 1) an existing national awareness of the associated sustainability challenges 2) a common reference benchmark to define sound practices, and 3) a strong position of the formal sector in the respective recycling chain.

In this chapter, we review various waste and scrap types that are available/arise in relevant quantities in LMICs and assess whether applying the ProBaMet approach (or a suitable adaptation) has the potential to address sustainability challenges that are often associated with them.

4.1 Aluminium

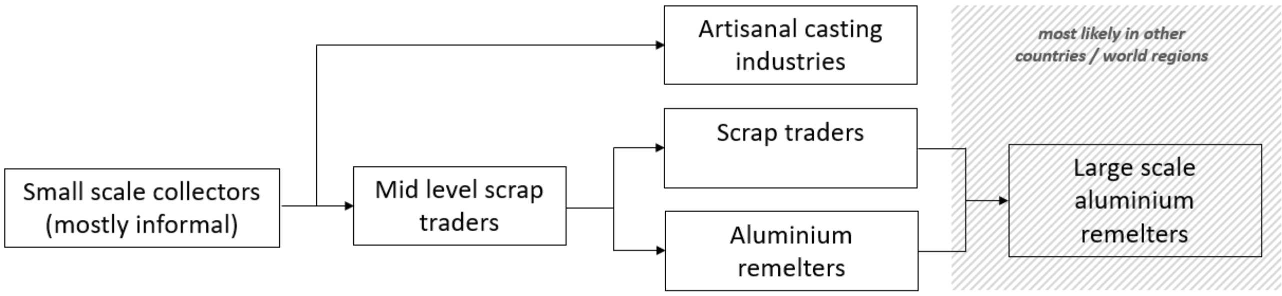
4.1.1 Description & reverse supply chain

Aluminium scrap is widely available in relevant quantities and collected in most LMICs due to its material value. Aluminium scrap is not a homogenous category and is usually classified into main types such as:

- Cast aluminium
- Aluminium rims
- Aluminium sheets
- Aluminium gutters / siding
- Aluminium cans
- Aluminium wires
- Dirty aluminium

In LMICs with limited industrial diversity, domestic demand for secondary aluminium is often limited to artisanal production, which mostly uses cast alloys.

Figure 4-1: Current reverse supply chain for aluminium scrap in LMICs (Sub-Sahara Africa)



Source: Authors' own illustration

Most aluminium scrap is collected for export, either as scrap or after melting into ingots. Remelters sort into different alloys and grades before melting. This sorting step is crucial to maintaining and increasing scrap value, as it determines the final alloy qualities. Public knowledge on sorting methods and qualities in facilities in LMICs is limited. Exporting entities (scrap traders, aluminium remelters) tend to be registered businesses, as a formal business status is required to participate in international (commodity) trade.

Figure 4-2: Impressions from aluminium recycling practices in Sub-Sahara Africa

1: Bailed aluminium cans for export

2: Artisanal production of cooking pots from cast alloys

3: Aluminium sheets from fridge recycling

4: Bailed aluminium sheets for export

Source: Oeko-Institut

4.1.2 Sustainability challenges

4.1.2.1 Social aspects

As with most informal scrap collection activities, poor working conditions are widespread and associated with the hazards of activities carried out (dismantling of products and installations → risks of injury, participation in traffic → exposure to pollution, accident risks). Moreover, incomes are generally low and there are no social security measures absent (apart from those associated with personal social ties). Child labour may be an integral part of some informal collection networks and usually concerns underaged adolescents (between 12 and 16 years old) involved in scrap collection. Some light work (e.g. collection of aluminium cans) may also be carried out by younger children.

The risks described are also linked to the precarious situation of the informal sectors (mostly poverty-related activities), which in turn are closely linked to general economic conditions and welfare systems. Structural improvements in this sector are therefore difficult to achieve with one-dimensional interventions. While measures such as training and provision of PPEs, use of reflective vests etc. can reduce some occupational risks, there is often no guarantee that such measures lead to long-term improvements.

4.1.2.2 Environmental aspects

In most cases, the collection and dismantling of scrap metal does not have a significant environmental impact. Exceptions to this are the following situations:

- Dismantling of electrical and electronic equipment and vehicles with improper disposal (or even burning) of non-valuable residues and materials;
- Burning of cables to recover the metal cores[7];
- Recycling of fridges with uncontrolled release of cooling gases and foaming agents;
- Some types of capacitors containing polychlorinated biphenyl (PCB)[8].

When aluminium is remelted, the scrap is heated in a furnace. In such settings, foreign materials (e.g. colour coatings) are also heated and form various types of organic pollutants that must be removed/destroyed in a suitable off-gas treatment system.

4.1.3 Suitability of the ProBaMet approach

4.1.3.1 Opportunities

- Aluminium scrap is a widely traded commodity with significant material value. Strong demand for responsibly sourced secondary aluminium can therefore provide an incentive to mitigate sustainability risks in low- and middle-income countries and may also act as a driver for quality-related improvements in the supply chain (particularly in the context of scrap sorting processes).

[7] Although many cables have an aluminium core, the focus during open burning is usually on recovering copper. Since all recovered metals take on a brownish colour due to the open burning process, aluminium from open cable burning is usually not sold to aluminium traders, but (intentionally or unintentionally) sold as copper scrap.

[8] PCB was internationally banned by the Stockholm Convention in 2001. Thus, PCB is only found in capacitors manufactured before 2001. The issue of hazardous PCB in capacitors is mainly relevant when decommissioning old power installations.

- Exporters of Al-scrap and remelted alloys are usually registered businesses. As the trade requires the shipment of relevant quantities, these players usually have their own storage and processing sites. These aspects are important prerequisites for the application of the ProBaMet approach.

- Cooperation between aluminium scrap exporters and remelters in LMICs and aluminium-consuming industries is likely to be in the core business interest of both sides, since a transfer of know-how in scrap sorting methods would likely increase the added value (and thus the economic returns) in scrap trading and in the remelting industry. Likewise, improved sorting would make the secondary aluminium supply from LMICs more attractive to the consuming industries.

4.1.3.2 Challenges

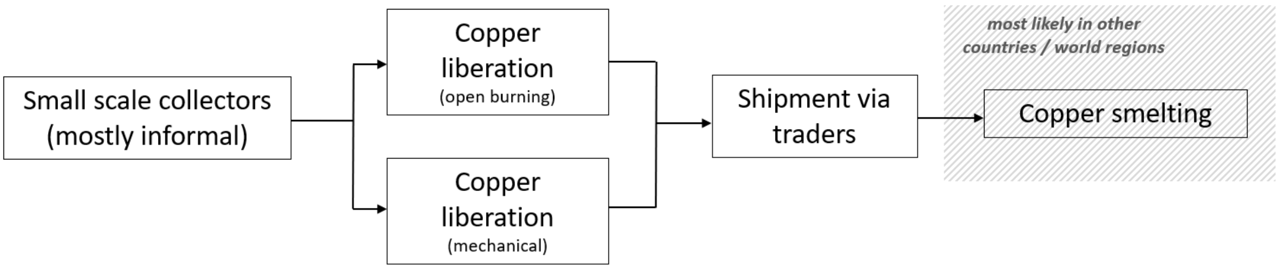
- Many sustainability challenges are associated with scrap collection and preprocessing, which are usually in the hands of the informal sector. Registered exporters (traders and remelters) can have some influence on collection and preprocessing practices, but this influence should not be overestimated, as off-takers (exporters) have limited ability to verify the implementation of minimum standards in their supply chains[9].

4.2 Copper

4.2.1 Description & reverse supply chain

Because of its excellent electric conductivity, copper is used in almost all types of electrical and electronic equipment. Due to its availability and its high material value, copper scrap is retrieved, collected, and traded all over the world. In many applications, copper is closely linked to other materials such as electric isolation material (e.g. PVC and PE of cables) and ferromagnetic steel (e.g. in electric motors and transformers). Secondary copper markets focus on liberated cooper, whereby these non-copper materials are excluded. Thus, copper must be liberated and separated from other materials before being sold to smelters.

Figure 4-3: Current reverse supply chain for copper in LMICs (Sub-Sahara Africa)



Source: Authors' own illustration

Copper scrap liberation can be done in a number of ways, bearing in mind that the least expensive method (open burning of plastic-insulated copper scrap) is a fairly widespread approach, particularly conducted in informal scrap sector settings. Open burning is preferred because it requires no investments and very little manual labour. At the same

9 In ULAB recycling, the formal recyclers can request that batteries are delivered intact and with electrolyte/acid. While this sourcing policy does not change the informal nature of the supply networks, it can widely mitigate the hazardous and environmentally harmful practices of uncontrolled breaking and draining of batteries. By contrast, the Al-scrap supplied does not indicate compliance or non-compliance with minimum standards in the supply chain.

time, it can offer the possibility to increase the weight of the copper scrap to be sold to the trader – either by prematurely extinguishing of cable fires[10] or by adding other non-copper wire material[11]. Open cable fires (and open burning of other copper craps) are a major source of dioxins and furans (persistent organic pollutants – POPs).

There are alternatives to open burning and various mechanical processing methods such as cable stripping and granulation, but these require higher investment and operating costs (labour and/or energy).

Figure 4-4: Impressions from open burning of copper cables

Source: Oeko-Institut

4.2.2 Sustainability challenges

4.2.2.1 Social aspects

Social aspects are closely linked to the emission of pollutants (predominantly POPs – see below) and affect informal scrap workers as well as neighbouring population groups. Additionally, POPs may be transported over long distances and enter the food chain.

Further social aspects are linked to the informal nature of the scarp sector that carries out scrap collection and processing. These aspects are similar to those of aluminium (see section 4.1.2.1).

[10] So that some of the plastics prevails in a visibly unrecognizable form of a brown/black coating.

[11] Copper from open burning has a brownish/blackish colour, which makes it difficult to distinguish between materials with visual inspection.

4.2.2.2 Environmental aspects

Open burning of copper (mostly cables) is a major source of POPs emissions. Emissions commonly occur in urban or semi-urban environments and affect large populations.

4.2.3 Suitability of the ProBaMet approach

- Copper scrap is a widely traded commodity with considerable material value. Strong demand for responsibly sourced secondary copper can therefore incentivise the mitigation of sustainability risks in low- and middle-income countries.
- Exporters of copper-scrap are usually registered businesses. As trade requires shipment of relevant volumes, these players usually have their own storage sites. These aspects are important pre-conditions for applying the ProBaMet approach.

4.2.3.1 Challenges

- Sustainability challenges are associated with copper liberation using open fires, which is usually carried out by operators in the informal sector. Registered exporters (traders and remelters) can exert some influence on liberation practices (e.g. by applying a discount for copper from burning), but such systems can also be achieved at the next processing stage, the copper smelters.
- Positive stimulus can therefore be achieved through global purchasing practices of large copper smelters, which could send clear signals that copper scrap from burning is unwanted and is valued at a significantly lower price. The ProBaMet approach with push and pull factors within LMICs could contribute to such a mechanism.

4.3 Zinc from galvanised steel

4.3.1 Description & reverse supply chain

Zinc is used in a wide variety of applications, mostly in the form of brass, die casting elements or galvanized steel. From a volume perspective, galvanization accounts for the largest share with 57 % of global zinc consumption used in this way (International Zinc Association 2022b). Steel parts and components (galvanized or not) are usually collected at the end of their service life and sold to secondary steel plants. In most low- and middle-income countries, there is a high demand for secondary steel products such as iron rods for the construction industry. Therefore, in most countries there are corresponding electric arc steel plants – usually in industrial areas with a stable energy supply and a well-developed transport infrastructure.

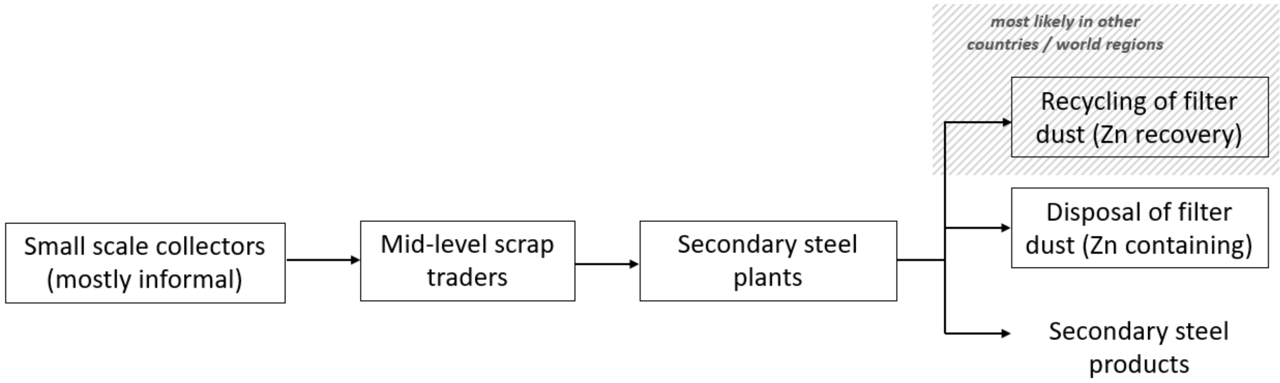
Scrap markets are therefore often local in nature, forwarding collected scrap to these smelters. Zinc that is fed into these secondary steel plants (in the form of galvanized steel) evaporates at the operating temperatures required for steel. The zinc then leaves the furnace with the off-gas stream and coagulates again into a solid state as soon as the off gas has cooled down. This zinc dust is usually collected together with other solid components from the exhaust gas in the baghouse filter systems of steel plants. On average, 25-30 kg of zinc-containing filter dust is produced per metric ton of secondary steel. The zinc content can vary between 3.8 % and 27 %, but in any case it is too high for a recycling in the same type of electric arc furnace (Yang Xue et al. 2022).

In addition, the off-gas typically contains relevant amounts of lead, cadmium, arsenic, dioxins and furans, most of which are captured in the baghouse filters (Rentz and Spengler 1997). Therefore, the filter dust has hazardous properties and requires sound management.

Sound management of the filter dust can be achieved either by controlled disposal in suitable disposal sites for hazardous waste, or by a controlled recovery process for the zinc contained, along with proper management of any other pollutants contained. The latter process is carried out by specialized companies such as BEFESA, which is located in Duisburg, and a number of other sites in Europe, North America and Asia. Shipment of filter dust to such companies requires notification according to the Basel Convention's Prior Informed Consent procedure and therefore incurs transport and logistics costs. Nevertheless, zinc recovery enables a certain economic return and offers possibilities for cost- and resource-efficient management of this highly hazardous by-product of steel recycling.

Alternative management options (local hazardous waste disposal) also incur costs and represent a loss of resources (zinc). If filter dust is disposed of improperly, it will cause significant environmental contamination.

Figure 4-5: Current reverse supply chain for zinc-galvanized steel scrap in LMICs (Sub-Sahara Africa)



Source: Authors' own illustration

From a global perspective, zinc recycling from secondary steel plants is well established but has not yet reached market saturation. It is assumed that a large number of secondary steel plants, particularly in various low- and middle-income countries, still do not use this management option and may resort to incomplete off-gas treatment and improper disposal practices for hazardous filter dust. Figure 4-6 No. 1 shows a secondary steel plant in Ethiopia with apparently no or non-functional off-gas treatment. In such plants, zinc and other pollutants are emitted uncontrolled, negatively impacting human health and the nearby environment. Figure No. 2 shows a disposal site for residues from industrial smelting and metal processing industries in Ghana. If filter dust from secondary steel plants is disposed of in such landfills, there is a high probability that some of the material will be transported by rain and wind to the nearby environment, adversely affecting soil and groundwater, including (where applicable) human health and food chains. In both cases, the zinc content of the filter dust is inevitably lost.

Figure 4-6: Unsound management of zinc-containing emissions from secondary steel plants

1: Emissions from a secondary steel plant in Ethiopia

2: Disposal site for residues from metallurgic operations in Ghana

Source: Oeko-Institut

4.3.2 Sustainability challenges

4.3.2.1 Social aspects

Social risks in (informal) collection networks are largely identical with those described for aluminium-scrap (see section 4.1.2.1). Social risks in and around secondary steel plants are primarily linked to emissions from the applied smelting processes and probably unsafe plant operations. In this context, a focus on collecting and sound recycling of zinc-containing filter dust would be a clear and measurable improvement of environmental and social situations, pre-supposing filter dust collection is sub-standard in the currently applied processes [12] .

4.3.2.2 Environmental aspects

As described in the sections above, improved collection and recycling of zinc-containing filter dust would have clear and measurable positive impacts in and around the addressed secondary steel smelters. It can firmly be assumed that the additional efforts for dust capture, transport and recycling are by far overcompensated by the environmental gains from such practices.

4.3.3 Suitability of the ProBaMet approach

4.3.3.1 Opportunities

- There is a significant demand for secondary Zinc and filter dust from secondary steel plants has been globally recognized as a major source of this material (International Zinc Association 2022a).

[12] The current management of zinc-containing filter dust from electric arc furnaces in LMICs has not yet been thoroughly investigated, so no data is available on the current practices and their market shares in LMICs (capture + recycling, capture + controlled disposal, capture + uncontrolled disposal, no capture). An exchange with experts from smelting and steel industry suggest that there may still be many plants using baghouse filters but not yet disposing of the collected dust in an environmentally sound manner (no controlled disposal, no recycling).

- Kick-starting the collection and shipment for recycling of Zinc-containing filter dust would significantly and measurably reduce emissions of, and exposure to hazardous substances in iron and steel recycling areas in LMICs. It would not only lead to a reduction of potential Zinc-emissions to the environment, but also other substances (heavy metals, organic pollutants) captured in the filter dust.
- Although most countries have no specific regulations for iron and steel recycling industries, general environmental legislation on industrial air emission limits exist in most countries and can be used as a legal basis to enforce the introduction of effective filter systems. Likewise, most national environmental authorities can define management requirements for certain types of hazardous waste and, amongst others, specify minimum requirements for the management of hazardous filter dust[13].

4.3.3.2 Challenges

- Awareness of negative impacts of secondary steel smelting may still be limited in many low- and middle-income countries and the plants primarily seen as strategic elements to satisfy the demand for steel products for the local construction sectors.
- Sound management of zinc-containing filter dust will – in most country cases – require transboundary shipment in-line with the procedures of the Basel Convention. As shipment of hazardous waste out of developing countries is often far from being an administrative routine process, so that related efforts can be substantial and cause significant delays and costs (PREVENT Waste Alliance & StEP Initiative 2022).

4.4 Electronic components

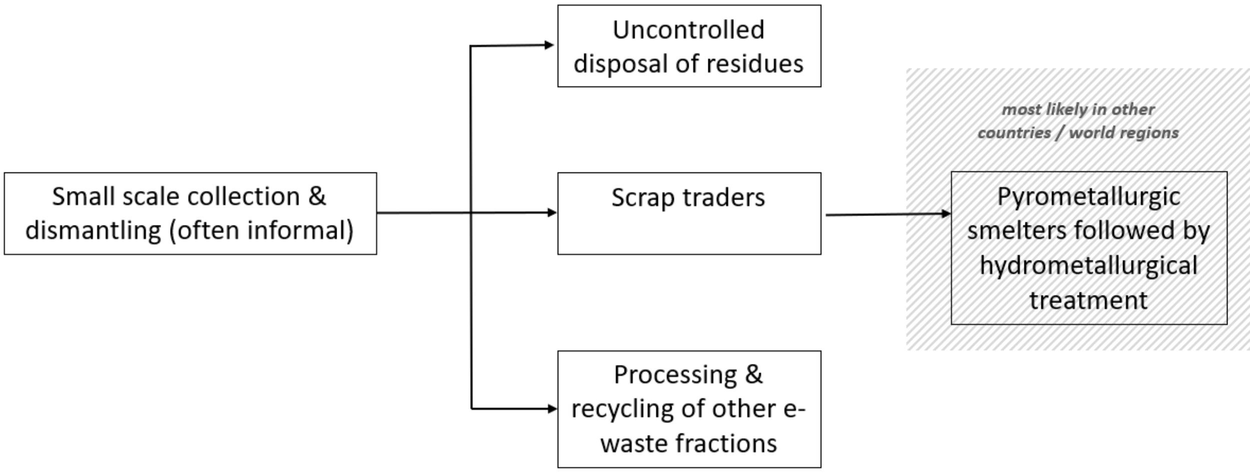
4.4.1 Description & reverse supply chain

Waste electrical and electronic equipment (commonly referred to as 'e-waste') is widely known to be a priority waste stream when it comes to growth rates, needs for separate collection, as well as sound end-of-life management. While e-waste encompasses a wide range of materials and material combinations, there is – from a raw material perspective – a particular focus on electronic components that contain high concentrations of copper, precious metals, as well as other technology metals. In most cases, such components consist of a printed wiring board mounted with microchips and other electronic parts. In the following, such assemblies are referred to as 'printed wiring boards (PWB)'.

Printed wiring boards are a major fraction resulting from the disassembly of electronic products such as computers, mobile phones, displays and others. PWBs are a widely traded commodity and are – for recycling purposes – commonly distinguished into 'low grade' (low concentrations of copper and precious metals), 'medium grade' (medium concentrations of copper and precious metals) and 'high grade' (high concentrations of copper and precious metals).

[13] Such minimum requirements are usually a condition for the granting/renewal of environmental licenses. Subsequently, non-compliance can lead to sanctions, including fines and/or the withdrawal of the license.

Figure 4-7: Current reverse supply chain for electronic components in LMICs (Sub-Sahara Africa)



Source: Authors' own illustration

Recycling of printed wiring boards is commonly done in hydrometallurgical copper smelters that produce an interim copper alloy ("matte") from where copper and precious metals are extracted through hydrometallurgical processes. Recycling capacities are predominantly established in Europe, Asia and North America and smelters source PWBs and other input materials globally. Particularly high-grade PWBs have a high material value and are traded at prices of several thousand Euros per ton[14].

Figure 4-8: Impressions from extraction of electronic components in informal settings

1: Electronic components from (informal) e-waste recycling

2: Disposed residues from informal e-waste recycling

Source: Oeko-Institut

Due to these high prices, PWBs are commonly extracted from electronic equipment, either through informal operators, or registered businesses in the reuse and/or recycling sector. Transboundary shipment to recyclers is usually organized

[14] The exact prices depend on the material compositions, the raw material prices for copper, gold, silver, and palladium, as well as the transaction volume.

by registered companies, either e-waste recyclers, or commodity traders. Thus, the registered entities organising the shipment may not necessarily be the players that conduct the e-waste recycling process.

4.4.2 Sustainability challenges

4.4.2.1 Social aspects

The currently prevailing reverse supply chains of PWBs in sub-Saharan African countries are often dominated by informal sector activities in e-waste collection and dismantling. Social impacts entail the handling of hazardous components, precarious and dangerous working conditions, as well as the partial use of child labour (e.g. in collection and sorting activities). Social impacts are also tied to polluting practices that affect workers and other segments of the population living or working near e-waste handling and processing sites (also see section 4.2.2)

While the PWBs are usually traded and exported by registered businesses, many of these businesses do not have their own dismantling and processing facilities for e-waste and often operate as traders.

4.4.2.2 Environmental aspects

The main environmental challenge associated with the extraction, trade and recycling of PWBs is that a large proportion of them come from recycling processes (formal or informal) that focus solely on the extraction of recyclable materials, while other non-valuable and hazardous equipment parts are not treated. Thus, many hazardous and non-valuable fractions are disposed of in an uncontrolled manner or even burned. The trade and recycling of PWBs from many low- and middle-income countries is therefore associated with improper e-waste management practices that release of hazardous substances, even if the recycling of PWBs itself meets high standards.

4.4.3 Suitability of the ProBaMet approach

4.4.3.1 Opportunities

- PWBs are a widely traded commodity with considerable material value. Strong demand for responsibly sourced secondary resources from PWBs can therefore provide an incentive to mitigate sustainability risks in low- and middle-income countries.

4.4.3.2 Challenges

- Many sustainability challenges are associated with the collection and pre-processing of scrap, which is usually in the hands of the informal sector. Exporters can influence collection and pre-processing practices if they themselves process e-waste. Nevertheless, a large part of the market (and particularly the one with high sustainability risks) is characterized by supply chains, as shown in Figure 4-7, in which the influence of formal players on the practices of informal suppliers is limited.
- The situation regarding sound or unsound management of residues from dismantling is difficult to monitor, particularly for players based in other regions of the world.

4.5 Li-ion batteries

4.5.1 Description & reverse supply chain

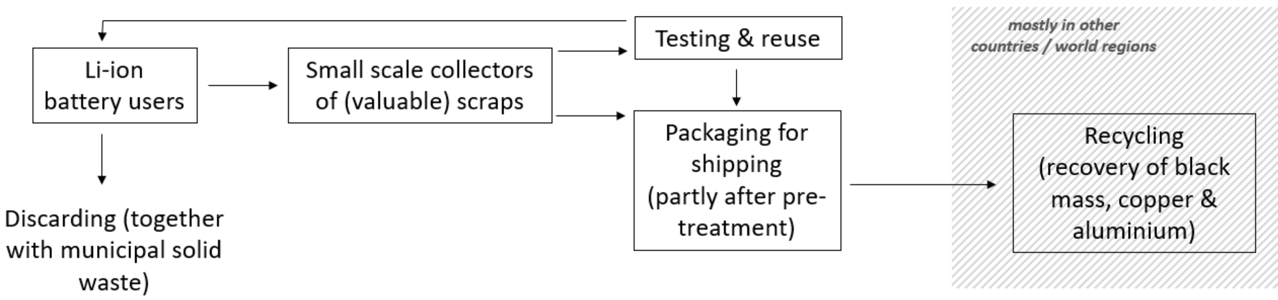
To date, the end-of-life Li-ion batteries in Africa come mainly from electronic applications (mostly mobile phones, tables, notebooks) and from solar power installations (e.g. solar home systems). Use in transport systems is still low and the associated quantities of discarded batteries are still negligible.

Batteries are either discarded together with the (obsolete) appliances in which they are installed or as a separate waste stream (e.g. after a battery has been replaced). The decision as to whether a battery is kept separately from other types of waste and fed into a special collection system depends largely on the associated value of the batteries: While some collection activities related to Li-ion batteries have been observed, particularly in urban areas, this type of scrap appears to be receiving much less attention than other metal-containing scrap types such as lead-acid batteries, aluminium scrap and copper scrap. This can be explained by the following factors:

- Recycling capacities for Li-ion batteries are very limited (or even non-existent) in most African countries. Subsequently, recycling is either limited to sub-standard processes (e.g. manual dismantling and separation of battery materials) or transboundary shipment to recyclers in other regions of the world. Due to the risk of fire and the hazardous nature of the batteries, such shipments are complex and involve significant costs (Manhart et al. 2022).
- The material value of Li-ion batteries is not very high and recycling is only profitable for LCO-subtypes[15]. Nevertheless, the price level of LCO-batteries usually does not exceed 500 €/t and requires shipment to recycling companies (Manhart et al. 2022).
- Battery cell testing and reuse is the most profitable segment as it does not require large investments and can benefit from a large demand for affordable equipment (e.g. power banks). Nevertheless, such reuse operations are typically limited to standard cells (mostly cylindrical, see Figure 4-10).

Besides these collection efforts that focus on material and reuse value, there are some additional collection efforts that aim to keep batteries separate from other waste streams. Examples include Li-ion battery collection efforts under e-waste compensation models such as Closing-the-Loop (Manhart et al. 2022) and the incentive-based collection of waste batteries in Ghana (Kyere 2024). While both systems generate end-of-life battery streams that require sound management, they are currently not representative for sub-Saharan Africa and require funding that goes beyond what can be financed by the recovery of embedded raw materials.

Figure 4-9: Current reverse supply chain for Li-ion batteries in LMICs (Sub-Sahara Africa)



Source: Authors' own illustration

[15] LCO batteries are commonly used in mobile phones, tablets and notebooks and have a comparably high cobalt content. Other Li-ion battery subtypes have a lower cobalt content or do not contain any cobalt at all.

Figure 4-10: Management of used Li-ion batteries in Sub-Sahara African settings

1: Copper foils from manual disassembly of Li-ion battery cells in a registered recycling company

2: Artisanal reuse of Li-ion batteries from notebooks

3: Accumulation and storage of Li-ion battery packs

Source: No 1: SRI-Project, No 2 & 3: Oeko-Institut

4.5.2 Sustainability challenges

4.5.2.1 Social aspects

End-of-life Li-ion batteries contain various hazardous substances that are released to the environment if not managed properly (see section 4.5.2.2) and expose persons living or working in the affected areas to these substances. Fire risks from improperly managed Li-ion batteries also have a strong social dimension, as fire outbreaks in waste management or disposal often endanger people due to fire hazards and/or smoke.

While separate collection and handling of end-of-life Li-ion batteries can reduce the risks described above, collection systems themselves can be put at risk by leaking and overheating batteries, which poses specific social risks for workers of such systems. Therefore, collection systems must be well thought out and include safety precautions throughout the collection and handling chain.

Reuse operations can also be associated with social risks, particularly during the use phase. These risks are associated with potentially unsafe (battery) products that can overheat, including worst-case scenarios involving fire outbreaks and explosions.

4.5.2.2 Environmental aspects

Li-ion batteries contain various substances of concern (Manhart et al. 2018), which are likely to be released when end-of-life batteries are disposed of in an uncontrolled manner. Environmental impacts can also arise from fires caused by overheating batteries (also see section 4.5.1).

4.5.3 Suitability of the ProBaMet approach

4.5.3.1 Opportunities

- A focus on Li-ion batteries could complement the current ProBaMet focus on lead-acid batteries. From the perspective of battery-using industries as well as regulatory agencies, such a focus can be useful as it would enable comprehensive approaches for the (rechargeable) battery sector.

4.5.3.2 Challenges

- Li-ion batteries are currently not in the focus of many formal waste management and recycling industries in sub-Saharan African countries, which limits the scope of cooperation with the ProBaMet approach. It is unlikely that a cooperation such as the one followed by the ProBaMet project would change this situation and lead to greater formal sector engagement in the collection and sound management of used Li-ion batteries.
- The ProBaMet approach is designed to modernise existing reverse supply chains. As Li-ion battery collection is still in its infancy in many low- and middle-income countries, the concept would only address a comparably small share of the theoretically possible quantities of end-of-life Li-ion batteries in the respective countries.
- The current trend towards LFP subtypes is likely to have many positive impact on battery safety and the use of (primary) raw materials (Manhart et al. 2018). Nevertheless, this also has the disadvantage that the values of end-of-life batteries will continue to decrease, thus further limiting the profitability of collecting and recycling such batteries. While applications such as mobile electronic devices will likely continue to use comparably valuable LCO-batteries, the increasing volume of LFP batteries will reduce the overall average material value per unit of EoL Li-ion batteries.

4.6 PV-panels

4.6.1 Description & reverse supply chain

There are various types of PV-panels available, but most systems are based on crystalline silicon, which dominates the market worldwide (>90 % market share). Thin-film technologies are more of a niche market of declining importance. In this segment, cadmium telluride is the most commonly used thin-film type, accounting for about 2 % of the global PV-market, with a downward trend (Wehrli forthcoming). For this reason, the following assessment focuses on crystalline type PV modules.

Crystalline silicon modules can be further categorized into poly- and monocrystalline silicon, a distinction that is of secondary importance for issues related to the end of life management.

The lifespan of PV-modules is estimated at 25-30 years for crystalline types and 10-20 years for thin-film technologies. Therefore, the volume of obsolete PV-panels is still limited in many LMICs.

The material compositions of crystalline silicon modules can be described as follows:

- **Glass:** To protect the cells, around ~2/3 of a module's weight
- **Frame:** Mostly made of aluminium
- **Crystalline silicon cells:** About 3 % of the module weight, mostly made of silicon with some aluminium and traces of silver, bismuth etc. (Chen et al. 2021).
- **Interconnector / ribbon:** 1-1.5 % of the module weight, mainly copper with some tin, lead and silver (soldering materials) (Wehrli forthcoming).
- **Backsheet:** Plastic to protect and seal the backside of the module. In addition, plastic sheets are used to encapsulate and protect the cells inside the module (mostly ethylene-vinyl acetate – EVA).

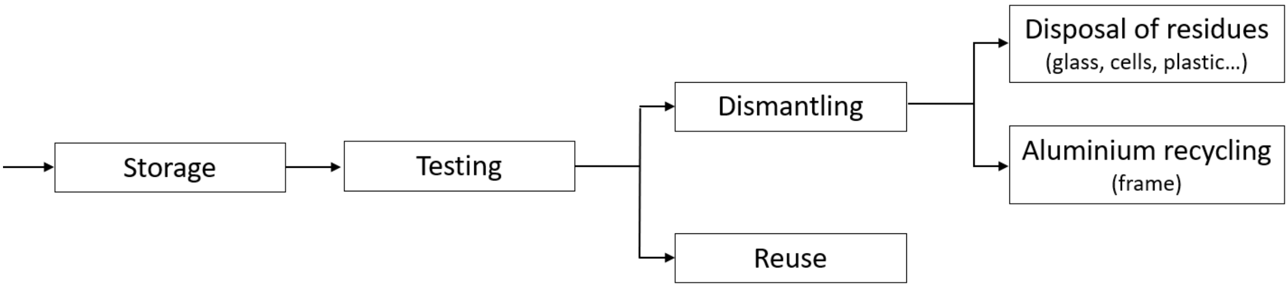
These compositions result in rather low material values for potential recycling: Both glass and crystal silicon are mainly based on silicon, which is one of the most abundant elements in the earth's crust. While highly purity silicon is the base material for the production of silicon wafers and microchips, these processes are not designed for post-consumer waste and therefore do not open recycling opportunities for end-of-life PV-modules.

In that context, it is reported and observed that end-of-life management of crystalline silicon PV panels in LMICs mostly refers to one or a combination of the following steps (Wehrli forthcoming):

- Testing and reuse;
- Extraction of aluminium frames and connecting cables and electronics for recycling;
- Extended storage or disposal of residual PV-panels.

More sophisticated recycling (e.g. of the front glass) is carried out in environments with mandatory and well-enforced take-back and recycling systems (e.g. based on a system of Extended Producer Responsibility, EPR).

Figure 4-11: Current reverse supply chain for PV-panels in LMICs (Sub-Sahara Africa)



Source: Authors' own illustration

Figure 4-12: Used PV-panels awaiting end-of-life management in Uganda

Source: Oeko-Institut

4.6.2 Sustainability challenges

4.6.2.1 Social aspects

Social impacts may be associated with the release of and exposure to hazardous substances. Further risks may be associated with risks of injury from sharp objects (e.g. glass) from broken panels.

4.6.2.2 Environmental aspects

Crystalline PV panels contain some substances that can have detrimental effects on human health and the environment. These are:

- **Lead (Pb):** Lead may be used in the solder material for connecting cells[16]. Some traces of lead are also contained in the crystalline silicon of the cells.
- **Antimony (Sn):** Antimony may be used in some glasses of PV-modules.
- **Fluor (F):** The backsheet covers of PV panels often consist of fluor-containing polymers. Burning such plastics can lead to the formation of hazardous hydrogen fluoride.

In addition, thin-film panels made of cadmium-telluride contain the hazardous heavy metal cadmium. Some model types may contain other substances of concern (Wehrli forthcoming).

4.6.3 Suitability of the ProBaMet approach

4.6.3.1 Opportunities

- There is a demand for sound end-of-life management solutions on the part of producers and solar system providers.

4.6.3.2 Challenges

- End-of-life PV panels are, apart from their aluminium frame, cables and connecting electronics, currently not in the focus of informal or formal waste sectors in LMICs, although there may be some activities related to testing and reuse. It is unlikely that a cooperation such as the one in the ongoing ProBaMet project would change this situation and lead to greater engagement by the formal sector in collection and sound management.
- The ProBaMet approach is designed to improve existing reverse supply chains. As collection and structured approaches to end-of-life management of PV-panels are still in their infancy in many low- and middle-income countries and will most likely not develop unless there is a strong and enforced EPR system in place, the ProBaMet concept would probably not make a tangible contributing to a solution.
- It is perhaps worth mentioning that alternative strategies, especially those focusing on the use of modules that are free of hazardous substances (no cadmium, no antimony, no lead in solders…), may be a more efficient way of mitigating many end-of-life sustainability risks linked to this waste stream.

[16] There are lead-free solders (e.g. tin and silver-based) that are the most common types of solders used in electrical and electronic equipment regulated by the RoHS policies (RoHS = Restriction of Hazardous Substances).

5 Synthesis & conclusion

The ProBaMet approach was developed to stimulate and realise systematic improvements in the recycling sector for used lead-acid batteries (ULABs). It combines push and pull factors, where push factors are regulatory approaches (including enforcement of standards) and pull factors are market incentives (preferential access to scrap, preferential connection to raw material markets). This study addresses the possibility of extending the ProBaMet approach to other countries, world regions and secondary raw material streams. From the analysis carried out in chapter 3 and 4 and the stakeholders consultation, the following (preliminary) conclusions can be drawn:

5.1 Applicability to other countries

Human exposure to lead is increasingly recognised as a major public health issue in LMICs. Although the management and recycling of ULAB is not the only potential source of lead emissions and exposure, it is often a very relevant one in and around ULAB recycling facilities and clusters. The ProBaMet approach is able to combine necessary steps around standard setting and enforcement with market incentives for regional best performers in ULAB recycling. This combination **can serve as a blueprint for concept expansion/replication in other low- and middle-income countries in Africa and possibly beyond.**

In this context, the **following additional aspects and elements should be considered:**

- **Government commitment to sector analysis and reform is an essential part of the approach.** While there are various African countries where awareness of this issue has already been developed, it is important that sector reforms be prioritised in the long term. Global initiatives in this area can significantly help to raise and maintain high awareness. Ideally, various countries initiate sector reforms on the basis of the ProBaMet concept in parallel and in close coordination, which could generate multiple benefits such as a) sending clear signals to investors that standards increasingly matter, b) open the possibility to exchange lessons-learned, c) using joint formats, e.g. in the field of positive listing of best performing companies.
- While strategies to upgrade the sector should be ambitious and target high standards in all ULAB recycling facilities and supply chains, **implementing change will require transition periods** during which many recyclers will not yet meet all minimum standards. While such transition phases should not be used as an excuse to delay the implementation of improvement plans, stakeholders involved (particularly from up- and downstream sectors) should also be aware that the approach will not immediately yield commercial recycling partners that fully comply with industry best practices.

  This also has **implications for due diligence approaches to battery disposal and raw material sourcing:** While due diligence should mitigate sustainability risks in supply chains, ideally by cooperating with fully compliant business partners, in many LMICs this may not be possible in the short term. Nevertheless, cooperations built on the condition of ambitious improvements can have tangible and measurable positive impacts in this sector and should also be considered in supply chain due diligence approaches.
- In addition to battery-using sectors and raw material-using industries, **commodity traders** should also be included in the process, as they often represent a central link between ULAB recyclers in LMICs and raw material-using industries in other countries.

5.2 Applicability to other secondary raw material streams

The analysis of different scrap and secondary raw material streams, as well as the exchange with stakeholders from industry, led to a mixed result regarding a possible expansion of the ProBaMet approach. As shown in Figure 5-1, none of the analysed streams features pre-conditions that are fully comparable to those of lead-acid batteries.

Figure 5-1: Matrix on ProBaMet success factors and analysed secondary raw material streams

	Existing national awareness	Existence of a common reference benchmark	Strong position of the formal sector	Interest of upstream / downstream industries in substantial improvements	Scale of challenge & improvement potential
Aluminium	medium	medium	medium	high	medium
Copper	high	medium	low	medium	high
Zinc	medium	medium to high	high	high	high
Electronic components	high	medium	low	medium	medium
PV panels	high	low to medium	low	medium	low
Li-ion batteries	High	low to medium	medium	High	medium

Source: Authors' own compilation

On the basis of the analysis carried out and the interactions actors in the non-ferrous metals industry, the **following windows of opportunity** for recycling partnerships arise:

- Parts of the **German aluminium industry** are interested in exploring partnership options with potential suppliers in LMICs. Although knowledge about applied sorting and remelting processes in LMIC facilities (particularly in Sub-Saharan Africa) is still limited, it is assumed that cooperation regarding aspects such as scrap sorting methods and scrap qualities could be in the interest of both sides. Improved sorting could increase the value of aluminium scrap and its applicability in the industrial cycle. Furthermore, various African countries (and also LMICs in other world regions) are major destinations for used car exports from Europe, resulting in a net loss of aluminium scrap for the European market. In view of the increasing demand for secondary raw materials in Europe, the German aluminium industry is aware that such global product and raw material streams must be considered in raw material supply strategies, including related cooperation arrangements.
- **Zinc from secondary steel plants** is likely to stick out in some way, as the associated raw material volumes are unlikely to have been developed in many LMICs, while and at the same time posing a significant risk to human health and the environment. An initiative bringing together secondary steel plants in LMICs, regulators and recyclers of zinc-containing filter dust could lead to significant improvements in emission control (reduction of heavy metals, including lead, and POPs emissions in LMICs) as well as in raw material recovery and supply. This view is shared by the German zinc industry and there is the interest to explore the topic further, e.g. with baseline assessments around some representative secondary steel plants in LMICs in cooperation with national authorities and filter dust recyclers.

Beyond these perspectives of the non-ferrous metals industry, the renewable energy industries operating in LMICs are interested in sound and developed disposal solutions for product/waste types such as Li-ion batteries, PV panels and electric components. The stakeholders of this sector have an understandable interest in sound recycling/disposal solutions for their entire waste stream. While this interest is perfectly legitimate, its implementation may require alterations to the ProBaMet concept, as some important prerequisites for success are not met (see Figure 5-1). Most striking is the still weak development of formalized counter-industries in many LMICs in these product/waste segments.

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