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Transition to sound recycling of e-waste and car waste in developing countries
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Lessons learned from implementing the Best-of-two-Worlds concept in Ghana and Egypt

A synthesis report of the project Global Circular Economy of Strategic Metals – Best-of-two-Worlds approach (Bo2W)(FKZ 033R097A – D)

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Authors

Dr. Matthias Buchert, Andreas Manhart, Dr. Georg Mehlhart, Stefanie Degreif, Daniel Bleher, Tobias Schleicher (Oeko-Institut)

Dr. Ir. Christina Meskers, Marcel Picard (Umicore)

Franziska Weber, Sascha Walgenbach, Torsten Kummer (Johnson Controls Power Solutions)

Dr. Rolf Blank (Vacuumschmelze GmbH & Co. KG)

Dr. Hossam Allam (CEDARE)

Jürgen Meinel, Vivian Ahiayibor (City Waste Recycling)

Head Office Freiburg
P.O. Box 17 71
79017 Freiburg
Street address
Merzhauser Strasse 173
79100 Freiburg
Tel. +49 761 45295-0

Office Berlin
Schicklerstrasse 5-7
10179 Berlin
Tel. +49 30 405085-0

Office Darmstadt
Rheinstrasse 95
64295 Darmstadt
Tel. +49 6151 8191-0

info@oeko.de
www.oeko.de

Partners

Johnson Controls · umicore · VAC · City Waste Recycling Ltd. · CEDARE

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Abbreviations

Bo2W	Best-of-two-Worlds
CRT	Cathode Ray Tube
CSR	Corporate Social Responsibility
CWR	City Waste Recycling
EEE	Electrical and Electronic Equipment
EoL	End-of-Life
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
GASDA	Greater Accra Scrap Dealers Association
HDD	Hard Disk Drives
ICT	Information and Communication Technology
NdFeB	Neodymium Iron Boron
NGO	Non Governmental Organization
PWB	Printed Wiring Board
SME	Small and Medium-sized Enterprises
ULAB	Used Lead Acid Batteries
VAC	Vacuumschmelze

1. Background of the Bo2W concept

Unsound management of e-waste in developing countries and emerging economies is regularly addressed by NGOs, journalists and scientists and is identified as a major source of pollution in urban environments (Kuper & Hojsik 2008; Puckett et al. 2005; Sepúlveda et al. 2010; Zhao et al. 2008). In most cases, the unsound recycling and disposal practices of informal scrap sectors are identified as the main sources of pollution and health hazards for waste workers, close neighbours and often residents in surrounding urban areas.

More detailed studies of practices in informal recycling clusters reveal that some of the practices used, such as wet chemical leaching of printed wiring boards (PWBs), are not only major sources of environmental and health hazards, but also quite inefficient in recovering materials (Keller 2006). In today's globalised world, where it is projected that developing countries and emerging economies will soon overtake industrialised nations in terms of e-waste generation (Yu et al. 2010) and the size of vehicle fleets (World Health Organization 2014), such inefficiencies have important repercussions on global recycling rates. If the current situation is not improved, global recycling rates of valuable metals (for instance lead, copper, gold) and of critical metals as defined by (European Commission 2014) and are likely to remain at low levels – despite research and improvements in high-tech processing.

In order to overcome such structural problems, the Best-of-two-Worlds (Bo2W) concept was developed by various members of the StEP Initiative[1] (Meskers et al. 2009, Manhart 2011; Wang et al. 2012). Its core is based on the idea that recycling can be optimised by deploying locally available comprehensive and well-guided manual dismantling practices, which are then linked to globally available highly efficient state-of-the-art end-processing facilities. While comprehensive manual dismantling can yield output fractions of high purity and value (Chancerel 2010; Gmünder 2007; Salhofer et al. 2009), the feasibility of deep dismantling is strongly dependent on labour costs. Thus, comprehensive manual dismantling is an important recycling option for many developing countries and emerging economies where labour costs are comparably low and the need to create decent employment is high. Complimenting this, state-of-the-art end-processing facilities require economies of scale and investments often totalling several million Euros. This is particularly the case for complex and non-ferrous metal fractions such as printed wiring boards (PWBs) and rare earth magnets.

Thus, such investments cannot be made in each country. Instead of developing sub-standard and inefficient end-refinery capacities, it is therefore advised to link local pre-processing operations to state-of-the-art end-processing facilities, also in cases where this requires long-distance transport of fractions. Of course, this concept does not imply that developing countries and emerging economies should not develop their own end-processing capacities at all. Such capacities (e.g. in steel-recycling) should be promoted and used wherever possible in order to increase the local value-added. Nevertheless, certain types of end-processing are quite risky to the environment and human health, such that any decision to promote local capacities should be carefully evaluated and monitored.

It is also important to stress that "the Best-of-two-Worlds philosophy" adopts a labour intensive approach following good environmental and social standards, which preserves abundant jobs for the informal sector with improved working conditions" (Wang et al. 2012). It is therefore not only a concept to increase recycling rates, but also a model to transform locally informal and often highly

[1] StEP = Solving the E-waste Problem Initiative

polluting recycling industries in labour-intensive and environmentally and socially sound operations.

In this context, it must also be emphasised that the Best-of-two-Worlds philosophy fully refrains from a direct or indirect promotion of e-waste trade from industrialised countries to developing countries and emerging economies. Although it might be argued that the Best-of-two-Worlds model could be supported by increased e-waste imports, the reality of recycling gives us a strong reason against such claims: to date, the Best-of-two-Worlds model is only successfully applied in small niche markets, while the bulk of e-waste and other complex waste types in developing countries and emerging economies is not managed in an environmentally sound manner. It is highly unlikely that this situation will fundamentally change in the next years. A consequent implementation of the *Basel Convention on the Control of Transboundary Movements of Hazardous wastes and Their Disposal* is therefore an important pre-requisite for sound e-waste recycling globally.

It is also clear that a stringent control of transboundary movements alone cannot help to solve local waste management and recycling problems in developing countries and emerging economies due to the rising amount of e-waste and car-waste from local sources. Therefore, concepts such as the Best-of-two-Worlds model need to be applied in practice and adapted so that they can be rolled-out and replicated globally. While the Best-of-two-Worlds model has already undergone first pilot implementations in China and India (Wang et al. 2012), implementation on the African continent has so far been lacking. This project aimed at testing the Best-of-two-Worlds model on a pilot scale in Ghana and Egypt (see chapter 2).

By doing so, the project team explored the strengths and weaknesses of this model, in particular in the contexts of these two countries (see chapter 3). While many positive aspects of the model could be confirmed in practice, the exercise also revealed some structural problems, which are mostly linked to the fact that the model is in competition with other recycling models that are currently in an economically superior position (see chapter 4).

Based on this analysis, the project identified strategies to overcome these structural barriers (chapter 5) and derived recommendations on how to continue with the development and implementation of the Best-of-two-Worlds concept (chapter 6).

2. The BMBF-funded Bo2W project

The Bo2W project sponsor, the German Federal Ministry of Education and Research (BMBF), sought to test the Bo2W concept in African practice. The consortium, managed by Oeko-Institut and joined by Umicore, Johnson Controls and Vacuumschmelze (VAC) was supported in local implementation by City Waste Recycling Ltd. (Ghana) and CEDARE (Egypt). All partners combined their strengths in leading companies in the field of critical metals recycling and applications with environmental research and project management capacity as well as strong local presence in Ghana and Egypt. The project was carried out between June 2012 and October 2015.

The Bo2W project aimed at supporting the establishment of environmentally sound collection and recycling systems for e-waste and car waste in Egypt and Ghana. By linking local recycling initiatives with international markets for specific recycling fractions, the project also aimed to improve the recovery of valuable and critical metals from end-of-life vehicles and e-waste and to close global material cycles in a sustainable manner.

To achieve this, the project followed the “Best-of-two-Worlds approach” (see chapter 1), which aimed to combine the strengths of recycling systems in developing countries with those of industrialised countries. The approach is characterised by the following principles:

- use local refining capacities whenever available and appropriately performing;
- export fractions that cannot be refined locally to high-tech facilities;
- develop sound solutions for all recycling fractions (valuable and non-valuable);
- let recycling systems in developing countries take over as many parts of the value chain as possible from an environmental and economic perspective;
- permit recycling systems provide decent jobs according to international labour and health and safety standards;
- closely cooperate with relevant authorities and stakeholders;
- Fair and transparent prices for recycling fractions;
- not permit direct or indirect involvement in illegal waste trade.

To achieve the project goals, Oeko-Institut, a leading independent research institute on sustainability issues, gathered selected partners from European industry and well-recommended local partners in Ghana (pilot country for West Africa) and in Egypt (pilot country for North Africa). Oeko-Institut delivered continuous scientific support and expertise for the project consortium and was responsible for the overall management of this international collaborative project with partners from Germany, Belgium, Ghana and Egypt.

Umicore is a global materials technology and recycling group with its headquarters in Belgium, specialized mainly on precious and technology metals like palladium, gold, silver and many others. Umicore’s expertise on all aspects of recycling metals from e-waste, such as printed wiring boards (PWBs), mobile phones etc. and lithium-ion batteries, was a valuable pillar in the Bo2W project. Umicore delivered essential information for the local partners in Ghana and Egypt for optimized handling and separation of e-waste components including health & safety, business practices, economic feasibility and international transport. In Hoboken/Antwerp Umicore recovers in one of the world largest refining plant 17 different metals with very high recovery rates under state of the art conditions.

Johnson Controls Power Solutions is the worldwide leading company of starter batteries and innovative batteries for vehicles with a start-stop function. Leading car manufacturers and suppliers of spare parts are delivered from 35 subsidiaries of Johnson Controls, representing more than one third of lead acid batteries worldwide. The activities regarding sustainability are supported by first-class technologies, production methods and a strong commitment to recycling. The role of Johnson Controls in the Bo2W Project was to secure the information flow about all aspects of lead acid batteries and their recycling. Johnson Controls supported the local partner in Ghana for the proper collection, storage, handling and transportation of used lead acid batteries in preparation for the lead recycling in Johnson Controls’ state-of–the-art recycling plant in Krautscheid, Germany.

Vacuumschmelze (VAC) is one of the leading global manufacturers of special metallic materials that have exceptional physical and magnetic properties and related products. The division “permanent magnets” of VAC is the sole company outside of Japan and China which produces significant quantities of NdFeB permanent magnets. The mechanical, powder metallurgical part of production, which requires intensive know-how, is exclusively performed in Hanau, Germany. VAC’s role in the Bo2W project was to support local partners in proper manual dismantling of hard disc drives (HDDs) to remove NdFeB magnets containing the embedded rare earth elements

neodymium and praseodymium. The VAC supported the Bo2W project in identifying e-waste fractions that should contain NdFeB magnets. They recommended which magnet components would be most suitable for recycling and how to dismantle them. The VAC also supported the local Ghanaian and Egyptian partners in manually dismantling HDDs to remove the NdFeB magnets with the embedded rare earth elements neodymium and praseodymium.

The SME City Waste Recycling (CWR) Ltd. based in the Ghanaian capital Accra served as the local partner in Ghana in the Bo2W project. CWR was founded in 2008 in order to find a solution for disposing electronic waste in Ghana. CWR is working with various social groups in districts of Accra that are most affected, e. g. Agblobloshie, which has an obvious problem with e-waste. CWR trains young people there and also supports NGOs to organize seminars providing technical know-how for e-waste recycling. CWR recycles electronic and electrical equipment by disassembling and separating individual components such as electric cables, ferrous metals, aluminium, printed wiring boards, batteries, etc. CWR was welcomed into the consortium for its knowledge of the Ghanaian recycling market, the local stakeholder set-up, and the administrative procedures and requirements in Ghana. They acted as a local Ghanaian coordination hub and linked to international recycling partners.

The Centre for Environment and Development (CEDARE) in Cairo was the local Bo2W partner in Egypt. CEDARE's role in the project was to facilitate the necessary contacts to the new e-waste recycling companies in Egypt as well as to the different national authorities and NGOs working with the informal waste sector in Egypt. CEDARE was established in 1992 as an intergovernmental organization dedicated to applied environmental research and practical implementation of projects for the benefit of sustainable development. CEDARE is well networked in Egypt and Arab countries and plays an internationally recognized active part in secondary resource extraction within the StEP (Solving the E-waste Problem) network. The CEDARE board consists of ministries of Arab States as well as of Member States of the European Union.

Within the Bo2W project the consortium organized several expert meetings and stakeholder workshops in Accra, Cairo, Antwerp and Berlin. Detailed information (presentations) about those events as well as several Bo2W project sub-reports compiled by the Bo2W consortium can be found on the webpage www.resourcefever.org .

See chapter 7 (Annexes) with a list of the Bo2W project sub-reports.

3. Project activities and outcomes

The Bo2W project team has already published the project results in detail in several sub-reports and other publications (see chapter 7). For this synthesis report, a comprehensive summary is offered for the readers. For studying the detailed outcomes, the authors would like to refer to the above-mentioned Bo2W project sub-reports. For highlighting the project activities and outcomes in a focused manner the project team presents five spotlights in this chapter. A hallmark achievement for the Bo2W concept was involving Ghanaian and Egyptian authorities, local businesses (including informal recyclers), NGOs and other stakeholders.

3.1. Spotlight 1: Modelling the volumes

A key research task in the Bo2W project was estimating as accurately as possible current and future volumes of relevant end-of-life (EoL) devices, such as TVs, notebooks, desktop computers, mobile phones, lead-acid batteries, in Ghana and Egypt. From this data, the volumes of embedded target metals, like cobalt, palladium, gold, silver and lead, and other materials, such as plastics and

other non-valuables, were derived for the current recycling markets in Ghana and Egypt as well as the estimated developments in these two countries up to the year 2025. This kind of detailed information is highly relevant for current and potentially new business partners for Ghana and Egypt, like international recycling enterprises.

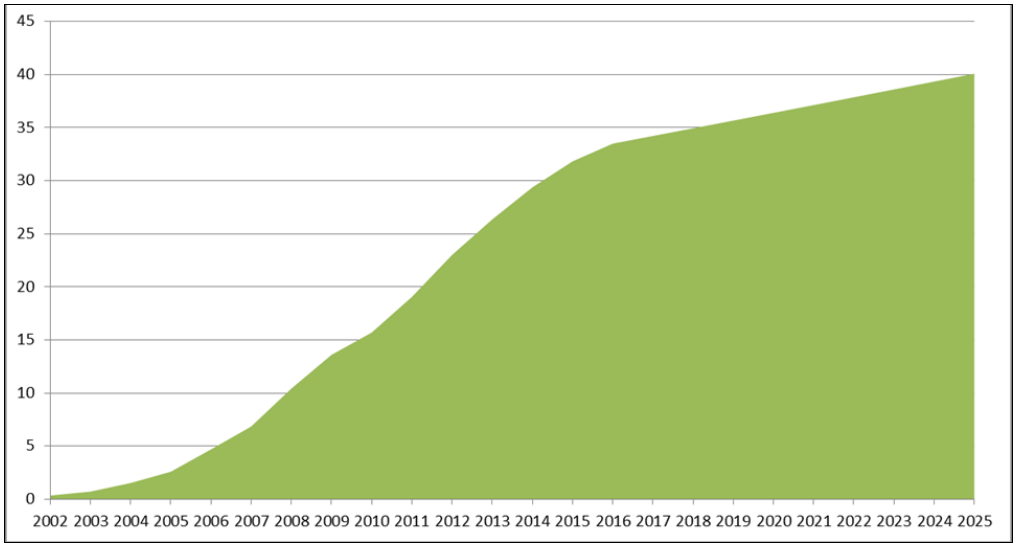
This data is of course also very important for other stakeholders, including local authorities and national regulatory bodies, due to the so-called 'negative value fractions' like CRT-glass or plastic components embedded in certain EoL devices. These components show a potential negative value for the recycling business and could cause serious health and environmental problems under the existing conditions in Ghana and Egypt. The Bo2W project delivered detailed information to these stakeholders in Ghana and Egypt about the scale of this problem and the necessary handling costs like for waste management plans and appropriate measures (see chapter 3.3).

The Bo2W project team achieved these results for Ghana and Egypt following these working steps:

1. Estimate and project the amount of selected devices in use (compiling stock information);
2. Calculate the amount of specific EoL devices (e.g. mobile phones) using device stock amounts and device lifetime;
3. Compile first-hand data from the Bo2W partners Umicore, Johnson Controls and VAC about the quantity (in g or kg) of target metals in specific EoL devices per unit (e.g. average silver content per mobile phone) as well as the mass of embedded negative value portions per unit;
4. Calculate and project the theoretical recycling potential (for 100% collection rate) of the different target metals in the various EoL devices and the volumes for important negative value components.

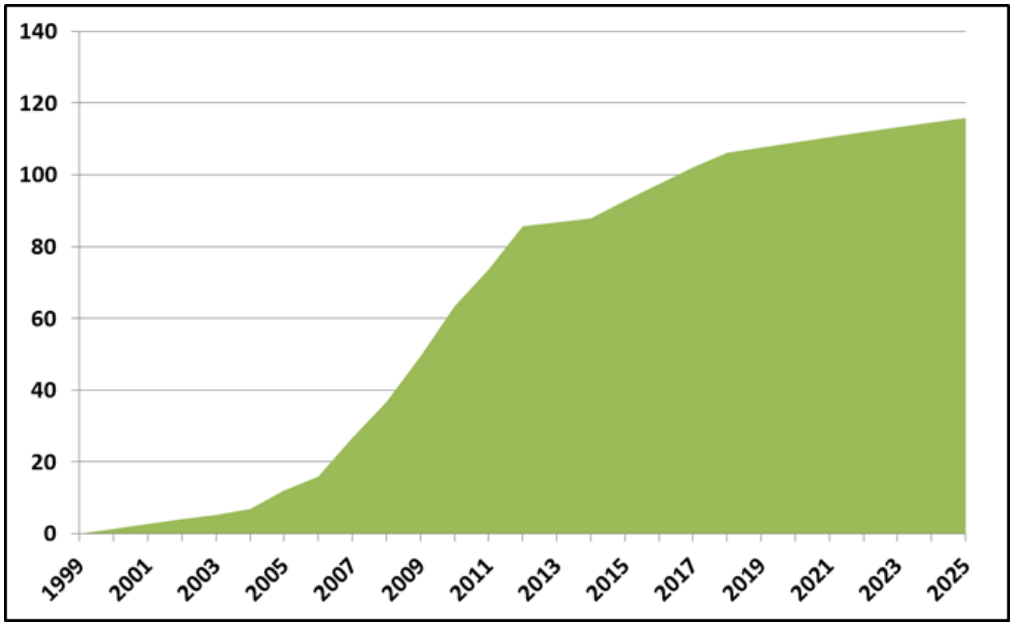
Figure 1 gives an example of the results produced in these working steps. All outcomes are documented in the published Bo2W country sub-reports for Ghana and Egypt (see references in chapter 7).

Figure 1 Projection of amount of mobile phones in use in Ghana from 2002 to 2025 [in million]



Source: Projections by Oeko-Institut

Figure 2 Projection of amount of mobile phones in use in Egypt from 1999 to 2025 [in million]



Source: Projections by Oeko-Institut

For the EoL mobile phones in Ghana, Figure 1 reveals the tremendous increase in recycling potential. The stock of mobile phones in use in Ghana will increase from near zero in 2002 to approximately 40 Mio. units by 2025. Similar results for other EoL products such as notebooks have also been calculated by the Bo2W project team. As figure 2 demonstrates, the results for Egypt's mobile phone inventory are generally parallel to Ghana's, though higher in absolute numbers due to a higher population and other country indicators. The Bo2W team revealed similar

trends for notebooks, desktop computers and TVs. The peak for CRT TVs and CRT screens will be reached in the coming years (see Bo2W country sub-reports for Egypt and Ghana, chapter 7).

Lastly, the calculation and prediction of volumes of relevant EoL products, including TVs, notebooks, desktop computers and mobile phones, in Ghana and Egypt supports general predictions found in previous studies that address e-waste generation in developing countries and emerging economies (See for instance Yu et al. 2010). The clear result is that the volumes for most of the EoL products will steeply increase in the next decade as a result of the growing in use stocks of these devices in countries like Ghana and Egypt.

This study also highlights the detailed expertise and first-hand knowledge offered by Bo2W partners Umicore, Johnson Controls and VAC. They delivered excellent information about the material composition of the different EoL devices for working step 3 of the overall approach (see above). By the time working step 4 was completed, the Bo2W partners could calculate and predict the EoL potential for the above mentioned target metals as well as the volumes for the negative value fractions. In total a cumulative recycling potential of several tons for precious metals like gold, silver and palladium and of several thousand tons per year for base metals like lead could be assessed (for detailed results see the Bo2W country sub-reports, see chapter 7). Exploiting this potential demands efficient collection, dismantling and end-processing procedures.

The elaborated data of the current and predicted potentials of EoL products and their embedded valuable target metals are key data for all kinds of stakeholders dealing with the waste and recycling sector in Ghana and Egypt. The results confirmed that both countries are rapidly growing markets for the collection, dismantling and end-processing business and offer strong business prospects. At the same time, it is expected that the current challenges will indefinitely become even more serious to handle threats to health and the environment, such as those caused by unsustainable procedures (open cable burning, etc.), and to deal with very low labour standards in the mostly informal recycling sector in Ghana and Egypt.

A further key task for the Bo2W project team was finding solutions to mitigate and avoid inappropriate treatment of negative value components like CRT glass and plastic components in Ghana and Egypt. Spotlight 3 below will describe this in more detail.

3.2. Spotlight 2: Training & knowledge transfer

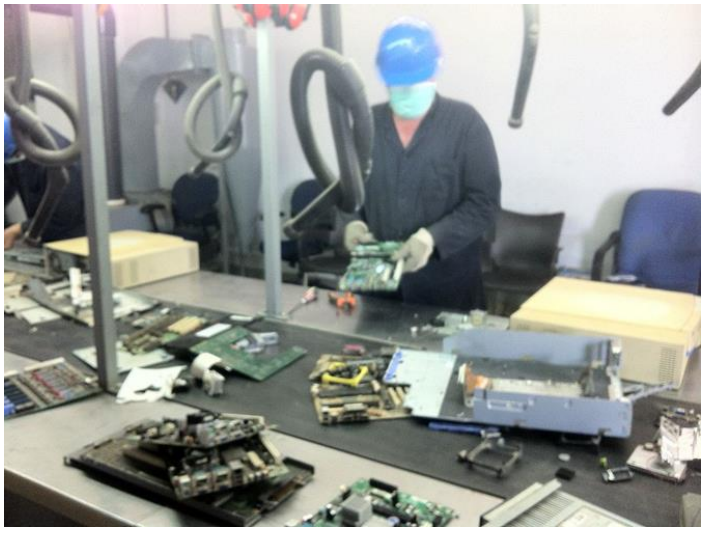
The Bo2W project trained local partners in Ghana and Egypt how to correctly dismantle EoL products manually and optimally and how to safely transport, package and store EoL products and separated material fractions. The Bo2W partners from industry (Umicore, Johnson Controls, VAC) played a key role through their active participation in developing training materials and in the training itself. The main addressees for this training and knowledge transfer were the local Ghanaian Bo2W project partner City Waste Recycling Ltd. and new Egyptian e-waste businesses like ITG and RecycloBekia. Training sessions were additionally offered for representatives of administration and other stakeholders from civil society. The following figures depict Bo2W partner activities from 2012 to 2015 on several project trips in Accra, Ghana and Cairo, Egypt.

Figure 2 Training on optimized e-waste dismantling; knowledge transfer of appropriate used lead-acid battery packaging (CWR premises in Accra, Ghana)

Source: Oeko-Institut

The project's training and knowledge transfer activities sought to address several main pillars of the Bo2W concept. Firstly, dismantling training should help the dismantling companies in Ghana and Egypt to separate and channel the different material fractions for subsequent recycling in an economically optimal way (see also Spotlight 3 below for further information). Secondly, knowledge transfer helps the local dismantling companies minimize health and safety risks for their employees and reduce hazardous environmental emissions. Overall, the optimized procedures should improve recovery rates for target metals (copper, palladium, silver, gold, cobalt, rare earths elements) and other material fractions and enhance labour conditions for employees.

Figure 3 E-waste dismantling at ITG premises in Cairo

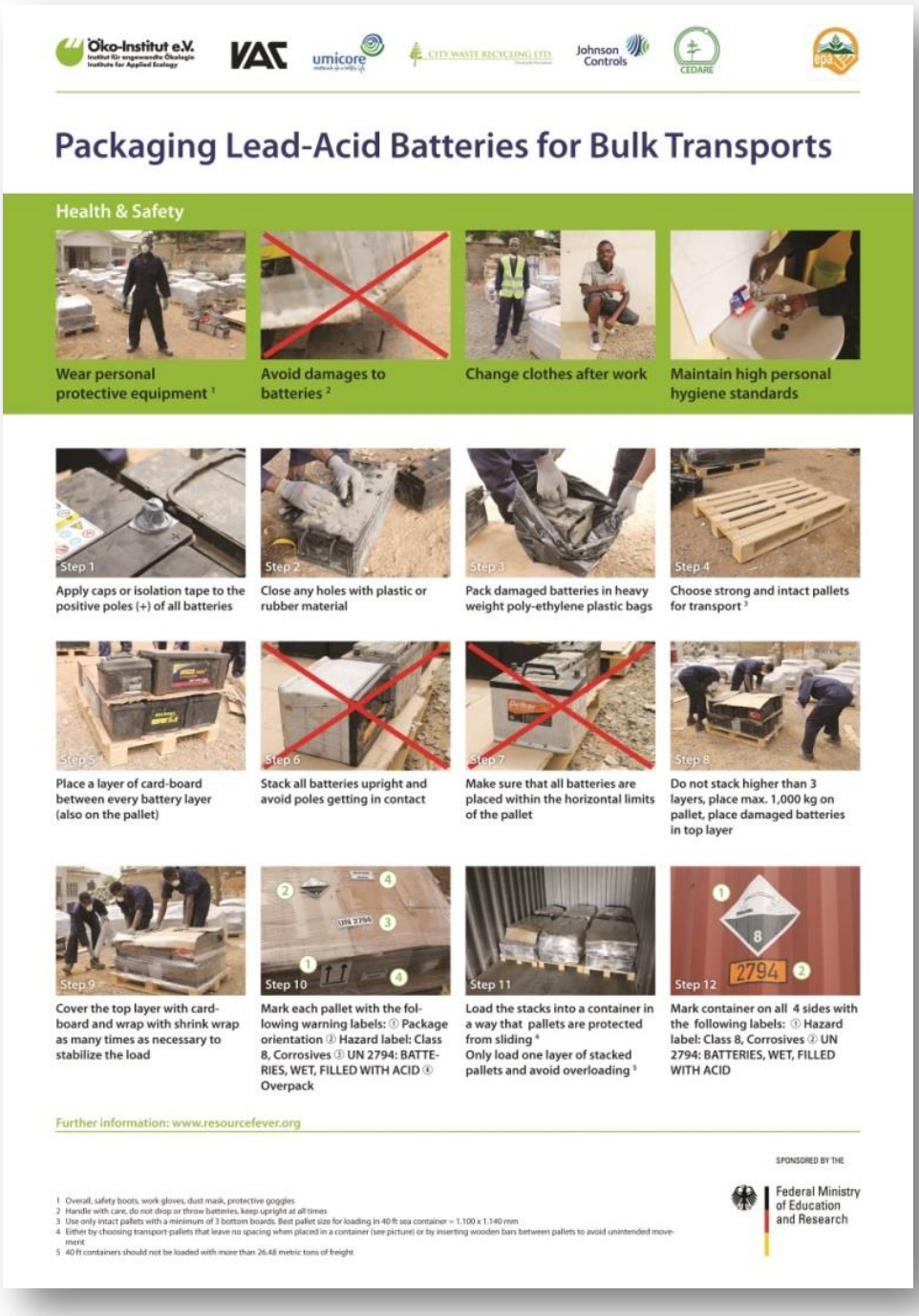


Source: Oeko-Institut

Posters depicting and describing CRT and desktop computer dismantling procedures and lead-acid battery packaging are one lasting result from the Bo2W project activities. Following advice from local Bo2W partners CEDARE and City Waste Recycling Ltd., the Bo2W team preferred producing these easy-to-understand posters over creating extensive text manuals. The posters are written for local dismantling companies in Ghana and Egypt and their employees. Targeting this audience, the posters were produced in English, French, Arabic and two local Ghanaian languages (Twi & Hausa) with a high proportion of pictures to address all literacy levels. The posters were

passed to pre-selected stakeholders in Ghana and Egypt and are also available online as pdf files (see chapter 7 for the Bo2W references and www.resourcefever.org). They may also be used in other countries. The following pictures demonstrate the English version of one poster.

Figure 4 Bo2W poster on packaging lead-acid batteries



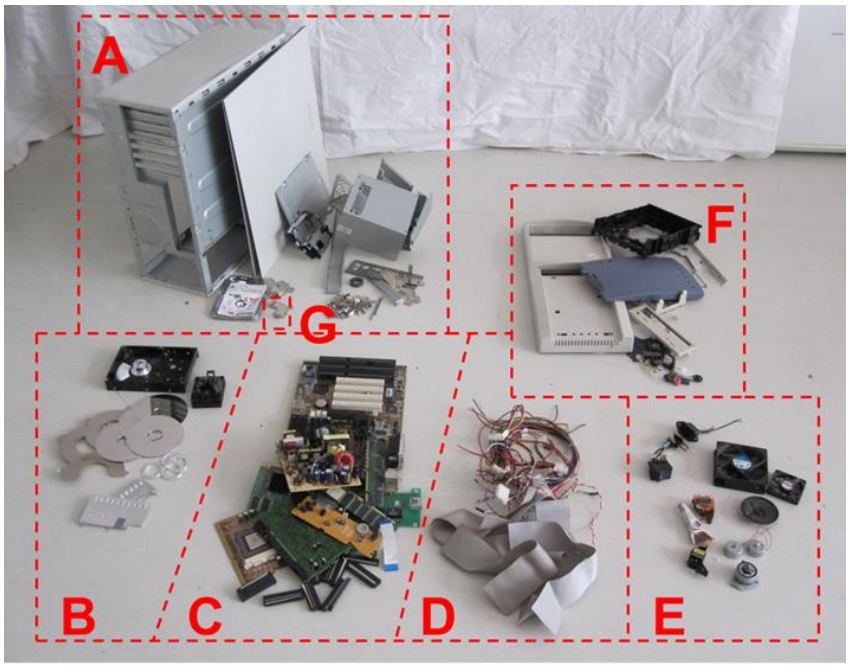
Source: Oeko-Institut

3.3. Spotlight 3: Supporting decision-making

The activities described under Spotlight 2 on training and knowledge transfer resulted in practical support for decision-making in dismantling SMEs in Egypt and Ghana. For instance, in 2012 one new Egyptian e-waste company planned to leaching printed wiring boards with acids to gain a liquid solution containing concentrated precious metals. The Bo2W partners Oeko-Institut and Umicore worked with this SME on an alternative approach following the Bo2W concept, which would deliver better results economically and environmentally and would allow the starting company to grow by focusing on collecting and dismantling devices and materials.

The following figure demonstrates the Bo2W team's approach for desktop computers.

Figure 5 Optimized dismantling and sorting of a desktop computer



A: Steel scrap
B: Aluminium scrap
C: Printed circuit boards
D: Cables
E: Copper-steel scrap
F: Plastics
G: Magnets

Source: Oeko-Institut

The information provided about optimized manual dismantling of e-waste was a key support for African SMEs starting in the e-waste business. Very often such companies have wasted workload and costs for separating the components too finely, which is definitely not necessary for achieving good recycling results. International recycling and refining companies have already optimized their subsequent separation (for instance mechanical steel – copper separation) and metal refining processes. Nevertheless, countries like Ghana and Egypt have committed human resources to optimized manual dismantling to ensure that the highly demanded material fractions are correctly separated and channelled to local companies (e.g. steel companies located in Ghana and Egypt for steel scrap) or to international partners (e.g. Umicore for printed wiring boards) in high qualities.

Another issue in Ghana is the campaign to stop openly burning cables. This informal-sector practice used to cheaply extract pure copper from cables is often found in many developing countries and emerging economies. However, this practice poses one of the most severe health and environmental threats linked to the informal e-waste business. The next figure offers an impression of this demanding challenge.

Figure 6 Open cable-burning at Agbogbloshie in Accra, Ghana

Source: Oeko-Institut

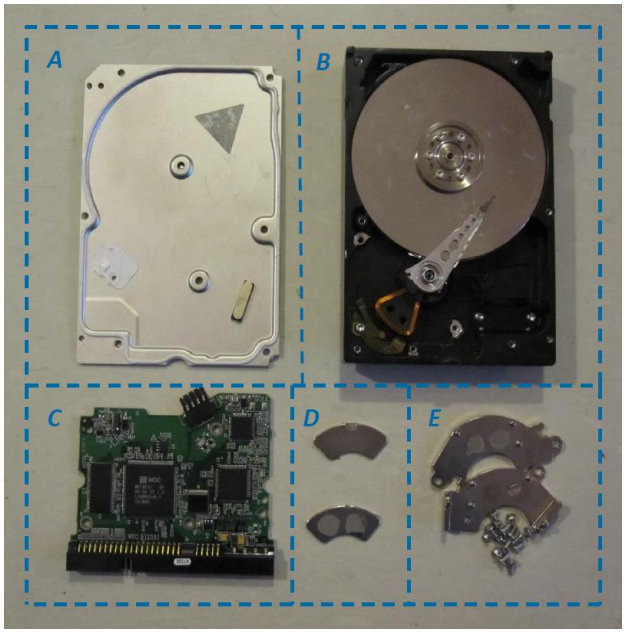
Just a few months after the official end of the Bo2W project, in an attempt to substitute cable burning in the informal waste sector, the Bo2W partner City Waste Recycling Ltd. (CWR) bought a mechanical cable shredder to separate copper from plastic insulation. CWR is able now to offer an environmentally sound alternative to open cable-burning in Accra. The informal sector in Accra is invited to co-operate with CWR by using this new better alternative.

The Bo2W partner Johnson Controls Decision initiated decision-making support for handling lead acid batteries. They informed the local partner CWR to accept only intact, used lead-acid batteries from suppliers, including the battery acid. This measure was deemed necessary to eliminate the informal waste sector's need to dump the hazardous battery acid on open ground or cut open batteries with machetes to access the lead plates. Such unsound practices are a serious threat for Ghana's environment. Consequently, the Bo2W partner Johnson Controls now accepts intact batteries from the local Ghanaian partner CWR. To completely stop the uncontrolled practice of dumping battery acid on open ground, the Bo2W partners convinced the Ghanaian EPA to not permit exporting used lead-acid batteries out of Ghana without the acid.

European Bo2W partners from industry and the local stakeholders in Ghana and Egypt carried out practical dismantling trials during several project trips to both countries. An illustrative example involved dismantling computer hard disk drives (HDDs) under Ghanaian working conditions. This

dismantling trial occurred on the CWR premises in Accra, Ghana, with tremendous support from the Bo2W partner VAC.

Figure 7 Dismantling depth of the hard disk drive



Source: Oeko-Institut

A: Lid (Aluminium); B: Case with platters and voice coil assembly (mainly Aluminium) ; C: Printed wiring board; D: Magnets; E: Magnet shoes and other steel parts

E-waste dismantlers in developing countries usually sell whole HDDs for aluminium recycling (almost 80% of HDD's weight is aluminium parts). Nevertheless, the Bo2W project analysed whether deeper separation of the HDDs could deliver better economic results for the dismantling company and better recovery rates for target metals. Besides the base metals steel and aluminium, HDDs also contain embedded copper and precious metals (fraction C: printed wiring boards) and rare earth elements (mainly neodymium in magnets: Fraction D). In a common dismantling trial at CWR, the Bo2W project team assessed all relevant parameters, including the dismantling times for different scenarios.

The results demonstrate that the separation of the HDDs into two fractions – PWBs for subsequent copper and precious metals recycling and the majority of the rest of the HDDs for aluminium recycling – delivers a clear economic advantage to the scenario without any separation of the HDDs. Separating PWBs and subsequently refining copper/precious metals could yield very high recovery rates (> 95%) for copper, gold, silver and palladium. When whole HDDs enter the aluminium recycling path, the main share of the precious metals are lost. These dismantling trial results apply to formal Ghanaian working conditions; however, sensitivity calculations showed that, even with much higher labour costs up to 8 USD/h (the basic scenario calculated with 0,77 USD/h), separating PWBs from HDDs could be economically feasible.

The dismantling trials also revealed only a small economic advantage from separating further fractions, mainly magnets for rare earths recovery. The falling rare earths prices over the last 3 years have made this option even less attractive. The Bo2W partner VAC tested the quality of a sample of separated magnets (neodymium iron boron – NdFeB – magnets) from CWR. It could be shown that steel impurities in the magnet material (screws, etc.) would cause additional pre-

treatment (and costs) to gain a pure enough NdFeB material for VAC to produce new magnets in Germany. The Bo2W partner VAC concluded that, from a technical standpoint, magnets separated from HDDs should be more suitable for chemical recycling processes for NdFeB-magnets. Such a chemical recycling process was developed in an R&D scale by the MORE project partners (Bast et al. 2014). The Bo2W's detailed results from the HDD dismantling trial in Ghana were already published in a single Bo2W sub-report (see chapter 7).

The Bo2W partners also focused on potential solutions for treating specific negative value fractions like CRT glass and plastics from electronic devices. CRT glass is critical due to high lead content. Plastic components from e-waste usually contain embedded brominated flame retardants. Within the Bo2W project, in-depth assessments were carried out on acceptable recycling or disposal options for these both negative-value fractions. The study concentrated on analysing the potential additional costs for environmentally sound alternatives compared to the uncontrolled dumping of these materials. For the last option the public must pay for addressing and managing the environmental impacts. Assessment results were already published in two Bo2W sub-reports (see chapter 7).

The primary conclusion for plastic components in lead-acid batteries is that, by using smart dismantling and separation strategies in combination with high-tech plastic recycling companies, a cost-neutral result should be possible. These results depend, to a large extent, on market prices for plastics. In the case of CRT glass, all investigated options would result in a negative economic scenario for the dismantling company. Indeed, environmentally sound recycling or disposal of CRT glass is a global challenge. The Bo2W team revealed several acceptable options for Europe, but all these options would likely deliver a negative value for African dismantlers. Exporting CRT glass from Ghana or Egypt to Europe would even create additional costs. Consequently, the Bo2W team supported local solutions within Africa, which would mean regulating official landfills with acceptable standards for the controlled disposal of CRT glass. As these landfills take time to construct, a pragmatic interim solution, such as safe stockpiling or sending to Europe, is required.

Since constructing CRT glass landfills entails costs, a funding system would need to be implemented for dismantling companies to equalize negative revenues. For instance, safe disposal of the expected cumulative volumes of CRT glass in Egypt would require total funding of about 4.5 million Euros through year 2025. The Bo2W team therefore recommended coordinated international activities in countries like Ghana and Egypt in order to raise the necessary funds for environmentally sound CRT glass disposal solutions.

3.4. Spotlight 4: Reaching out to stakeholders

Stakeholder consultations in Ghana and Egypt were a main task and activity from the beginning of the Bo2W project. To bring the Bo2W concept into practice (here as the pilot study in Ghana and Egypt), many local stakeholders had to be informed and convinced of the integrity of the Bo2W approach and the positive prospects the approach could bring to these two African countries. Strong stakeholder partnerships, with CEDARE in Egypt and City Waste Recycling Ltd. in Ghana, played a key role in the project's success. These local Ghanaian and Egyptian players were already in contact with many other stakeholders who impact policy and represent authorities, civil society and industry, including representatives from the existing informal waste sector. Oeko-Institut coordinated the contacts between the various local Ghanaian and Egyptian partners and the Bo2W industry partners (Umicore, VAC and Johnson Controls). This guaranteed successful knowledge transfer and laid a strong foundation for business relationships.

During the monthly phone conferences involving all Bo2W project partners, the several project trips to Ghana and Egypt were discussed and planned. Contact with representatives from the various Ghanaian and Egyptian stakeholders fulfilled a central element in the project trip agendas. In providing these contacts, the local Bo2W project partners facilitated important bilateral meetings. European Bo2W project partners, particularly Oeko-Institut and industry partners, gained direct contact with representatives from different ministries, including officers of important authorities like the Ghanaian Environmental Protection Agency (EPA), recycling company leaders (ITG und RecycloBekia in Egypt), representatives of the informal waste sector (for instance in Ghana with the leaders of the Greater Accra Scrap Dealers Association), representatives of involved NGOs (for example with Spirit of the Youth in Cairo) and many other stakeholders, sometimes even on vice-minister or minister levels.

With this bilateral approach the Bo2W project team could in many cases form a continuous, tight and constructive dialogue, a pre-condition for fulfilling the Bo2W project's objectives. One good example is the dialogue with the Ghanaian EPA, which is responsible in Ghana for notification procedures to export material fractions between the Tema seaport to Antwerp or Hamburg (see Spotlight 5). The numerous bilateral consultations were also used to invite selected stakeholders for upcoming Bo2W project events. The following main events were organized within the Bo2W project in Cairo, Accra, Antwerp and Berlin:

- Stakeholder workshop in Accra in June 2013,
- Several workshops with Green ICT Group in Cairo,
- Milestone Workshop in Hoboken (Antwerp),in November 2013
- Final stakeholder workshop in Accra in July 2015, and
- Closing Event in Berlin in September 2015.

The Bo2W team also invited and hosted selected guests from Egypt and Ghana to the main events in Europe, the milestone workshop at Umicore in Hoboken (close to Antwerp) and the Closing Event in Berlin. International guests had also the opportunity to visit the state-of-the-art metal refining plants at Umicore (specialised in recovering copper, precious metals and many other metals from e-scrap like printed wiring boards and other secondary materials at Hoboken, Belgium) and at Johnson Controls (specialised in recovering lead from used lead-acid batteries in Krautscheid, Germany).

Overall, the experiences of the described stakeholder consultation formed the basis for achieving the project objectives. These activities are recommended for similar approaches following the Bo2W concept in developing countries or emerging economies.

Figure 8 Group picture from the Bo2W milestone workshop (Nov. 2013 at Umicore in Hoboken/Antwerp)

Source: Oeko-Institut

3.5. Spotlight 5: Trial implementation

One of the Bo2W's main objectives was the trial implementation of the Bo2W concept in Ghana and in Egypt. This meant that, on a pilot scale, e-waste was manually dismantled locally. As well, lead acid batteries were appropriately handled locally. The separated fractions from both e-waste and batteries, for which suitable local refining capacities are not available, were exported to European state-of the art refining plants with Bo2W partners.

In Ghana, the local Bo2W partner City Waste Recycling Ltd. operates as a formal SME in the recycling sector, with experience in plastic recycling and e-waste dismantling. In Egypt, the situation is different because the local Bo2W partner CEDARE a scientific think-tank for different environmental issues, including e-waste, is not a dismantling company itself. Nevertheless, at an early stage of the project, the Bo2W team with CEDARE's support could identify two new companies that collect and dismantle e-waste. During the project (2012-2015) the Bo2W partners progressed remarkably in helping these two new companies develop market knowledge and skills in the Egyptian e-waste sector. For instance, one company started operations at a new dismantling line and the second enterprise experienced remarkable growth in the Egyptian scrap market. These companies progressed despite the difficult living and working circumstances following the Egyptian revolution in January 2011.

The situation for handling e-waste and lead-acid batteries is similar in Egypt and Ghana to most other developing countries and emerging economies worldwide, where the informal waste sector controls the largest share of the waste sector. Consequently, formal companies like City Waste Recyling Ltd. have to compete or cooperate with the informal sector in acquiring EoL devices. The remaining challenges will be discussed in chapters 4, 5 and 6.

Bo2W partners succeeded in implementing the pilot version of the Bo2W concept for exporting intact lead acid batteries from Ghana to Germany and printed wiring boards (PWBs) from Egypt and Ghana to Belgium. This trial implementation was made possible and backed by all the Bo2W project activities already highlighted in Spotlights 1-4. In this implementation, the local partners

sustainably dismantle material fractions so that Umicore could recover target metals like copper, gold, silver and palladium and Johnson Controls could recover lead in their high-tech metal refineries, with very high recovery rates and minimized impacts for the environment, in Belgium and Germany.

Bo2W partners from industry and local authorities in Ghana and Egypt supported completing the necessary paperwork for packaging and shipping several containers of waste materials from Egypt and Ghana to Europe. For other separated fractions like steel or aluminium, local refineries in Egypt and Ghana are the choice for the local partners. However, recycling lead acid batteries in Egypt makes sense because Egypt has large lead-acid battery manufacturing companies that rely on a large lead supply. Egyptian national regulations additionally prohibit exporting used lead acid batteries. In Ghana, such lead acid battery manufacturing capacities do not at all exist; hence, export is necessary.

The successful Bo2W concept trial implementation in Ghana and Egypt verified the feasibility of the overall Bo2W approach on a pilot scale. Several dozen tonnes of secondary materials have already flowed to Europe for refinement. Nonetheless, the Bo2W project revealed serious structural barriers which must be overcome for the concept to be implemented on a large scale in countries similar to Egypt or Ghana (see chapters 4-6).

Figure 9 Pilot implementation: City Waste Recycling Ltd., Accra, Ghana

Source: Oeko-Institut

4. Implementation barriers to the Bo2W concept

Despite the above-described outcomes and achievements of the Bo2W project, structural barriers for broad scale implementation of the Bo2W concept could be identified. Though the Bo2W partners of course anticipated practical barriers before starting the project, the team gained significant first-hand experience about serious structural barriers in the pilot countries Ghana and Egypt. Selected for their appropriateness for piloting the Bo2W concept, Ghana and Egypt are developing countries with common but also specific problem areas. The tremendous challenges for improving the waste sectors in these countries must consider generic and region-specific issues. In analysing these pilot studies, researchers and readers alike must recall that only a few short decades ago even advanced countries like Germany faced serious waste issues.

This study identified that the usual externalisation of costs for health & safety, environmental protection and acceptable labour conditions by the dominating informal waste sectors in countries like Ghana and Egypt poses the main barrier to widespread dissemination of the Bo2W concept. Companies internalizing these costs have a very large competitive disadvantage.

Collecting, treating and dealing with e-waste and car-waste secure incomes for many thousand people working in the informal waste business to allow daily survival. People working in the informal waste sector do not accept even small reductions in their immediate profits to respect environmental laws, health & safety provisions and basic labourer rights. The daily visible effects are the open burning of e-waste – mainly copper cables with insulation materials – the dumping of CRT glass and plastic fractions in trenches or lagoons (see next figure), the tipping of battery acids on the soil and many other hazardous and uncontrolled practices.

Figure 10 Uncontrolled dumping of negative value fractions at Agbogbloshie in Accra, Ghana

Source: Oeko-Institut

Therefore, the current situation in Ghana and Egypt concerning e-waste and car-waste has to be named an uneven playing field.

The widespread lack of basic environmental laws and regulations and/or the pending engagement of existing regulations in Ghana and Egypt even reinforce this uneven playing field. Many people

involved in the waste sector in these countries do not know anything about the often perilous effects of their daily practices. This was an obvious finding in the July 2015 stakeholder workshop in Accra. An internationally recognized expert on lead acid battery recycling informed the workshop's Ghanaian audience and the stakeholders from the informal waste business about the very serious health effects of lead poisoning. The questions and reactions of many participants indicated that knowledge of the serious or perilous impacts on human heath was direly lacking.

In Ghana, for instance, about 80% of economically active people work in the informal sector. This is a main reason why environmental and other regulations are not known or regarded at all and awareness of risks to their own health is not far developed. Regulation implementation and enforcement by authorities is very challenging in developing countries and could even lead to social unrest in the informal sector.

As a result of all the described structural barriers, SMEs like City Waste Recycling Ltd. in Ghana, which are committed to the Bo2W concept, suffer from unbalanced competition. The informal waste sector competitors have, in most cases, a clear economic advantage in more easily acquiring e-waste and car waste because costs for environmental protection are externalised. The Bo2W team's main proposals for overcoming these barriers are described in the following chapter 5.

5. How to overcome the barriers

As demonstrated in chapter 4, environmentally and socially sound recycling is currently not economically competitive with informal recycling practices in developing countries, which can – also from an economic perspective – be characterised by:

- No costs from taxes, fees, insurances etc.;
- Low incomes of workforce and absence of social security;
- Focus on valuable fractions only (cherry-picking);
- Externalisation of costs (high environmental impacts as a burden for neighbouring communities and the society).

This strategic disadvantage is particularly important in environments such as urban Ghana, where e-waste and used lead-acid battery (ULAB) collection is widely organised by (informal) collectors who offer cash money and convenient pick-up for households and businesses. Under such conditions, socially and environmentally sound recycling is not able to compete on a cost basis and will subsequently have severe difficulties in acquiring scrap for recycling.

These structural barriers were the main reason why the pilot implementation in Ghana could only address quite moderate volumes of e-waste and lead-acid batteries: despite a memorandum of understanding signed with the Greater Accra Scrap Dealers Association (GASDA) in February 2013 and various attempts to acquire e-waste and used-lead acid batteries (ULABs) for recycling, the volumes received by these means remained moderate. In most cases, these purchasing trials revealed that the informal Ghanaian scrap market – in particular in the urban centres – is well informed and highly competitive. While most entities and individuals that have moderate or large volumes of scrap to sell voiced their principle interest in business partnerships with the Best-of-two Worlds (Bo2W) project, it is common practice for them to compare price levels of various outlets shortly before committing to any deal. Thus, virtually all scrap material is sold to highest bidders regardless of their commitment to following sound practices. As the Bo2W model cannot

economically compete with informal recycling in Ghana, it lost these negotiations in almost all cases.

Unfortunately, it is very unlikely that this situation can be turned around through increased collection efforts in households. If a formal collection scheme is set up, the arising costs for infrastructure and logistics will likely increase the economic disadvantage of the formal system. Subsequently, the incentives that can be offered to businesses and households will be significantly below the level offered by the current informal collectors who operate with minimum profit margins, investments and running costs.

The project nevertheless identified various means that can help overcome these barriers. Although none of them provides the perfect solution to the described dilemma, it is highly recommended to bundle them into targeted strategies for sustainable transformation of the e-waste and car waste recycling industries in developing countries and emerging economies.

5.1. Improved access to downstream markets

Informal recycling industries also face economic disadvantages, which can mainly be grouped as follows:

- For many fractions like printed wiring boards, copper and aluminium, informal recyclers are not in a position to access downstream markets, which are mostly located abroad. These companies' informal nature excludes deals with large end-processing facilities that only work with registered companies. Furthermore, small informal recyclers often have difficulties producing the scrap volumes (e.g. several metric tonnes per fraction) needed for such direct business partnerships. As a result, the informal recycling sector depends on a variety of intermediaries. While some of these intermediaries purchase scrap directly in African recycling clusters, others manage storage and shipment. And indeed, intermediaries are not only limited to the African region. It is assumed that printed wiring boards in particular are also sold to scrap dealers located in other world regions who again forward the materials to end-processing facilities. While many intermediaries provide useful functions, such as organising storage and transport, the profit distribution for each of these systems is not very transparent.
- Complex trading chains allow for missing feedback-loops along the chain between end-processing units and recyclers. While end-processing units provide a comprehensive documentation of material quality to their suppliers, this information can only be utilised to optimise pre-processing if intermediaries do not withhold information.

As a consequence, direct business relationships between pre-processing companies and end-processing units should help to reduce the economic disadvantages of formal and sound recycling. This approach was actually followed in this Best-of-two-Worlds pilot implementation project and proved to have considerable strengths in both areas: higher prices for output fractions and establishment of feedback-loops from end-processing to pre-processing.

This strategy nevertheless also poses challenges:

- Assessment: Because many pre-processing companies in developing countries and emerging economies are newcomers, it is difficult for end-processing units to assess them. When due diligence aspects in raw-material supply chains become more important, the efforts to directly include small and medium recyclers become considerable.

- Financial security: By directly supplying end-processing units, pre-processing enterprises are also responsible for transport, logistics and pre-financing. Pre-financing is especially relevant since end-processing units usually only compensate for received materials after assaying. At the same time, pre-processing companies must also manage and finance scrap acquisition, pre-processing and transport. Consequently, pre-processing enterprises must maintain considerable financial means to bridge this cash-flow gap.

5.2. Start with B2B business

Large national and international companies often have CSR-policies that prohibit them to pass-on their waste to non-registered collectors or recyclers. Ideally, such companies also ask for relevant operating permits and a certificate for sound recycling and disposal. The e-waste generated by such companies is often quite attractive for recycling, as it mostly handles office-equipment with a positive net-value. This type of business-to-business (B2B) segment is an important niche market for sound recycling, as waste volume competition is not only based on price, but also on the level of standards.

In addition to large companies, the public sector is also an important consumer of e-equipment. In many situations, public institutions such as schools, universities and government agencies, stockpile significant amounts of obsolete equipment waiting further management. Generally, the public sector should play a leading role in waste management and should tender-out e-waste and car waste exclusively to companies that can prove they operate in line with ambitious environmental and health & safety standards. This strategy can be quite effective for start-up recycling companies to become established on the market and to implement and maintain high standards. Nevertheless, this strategy is naturally limited to a part of the market and not suitable to solve the problems from e-waste and car waste generated by private households and small- and medium-sized enterprises.

Government can support this strategy by two means:

- Tendering its own waste volumes exclusively to enterprises that apply high standards;
- Requiring companies to apply the same policy.

5.3. Incentives versus policing

Taking into account the scale of pollution and health impacts caused by unsound e-waste and ULAB management, sanctioning mechanisms (commonly referred to as “policing”) are in any case an important policy tool. Nevertheless, its effects are limited in environments where a large portion of the population is earning its income in the informal economy. This is the case in Ghana, where it is estimated that 80% of the workforce operates under informal conditions (Osei-Boateng & Ampratwum 2011). In Ghana, informal collectors and recyclers are mostly active in this business because of a lack of economic alternatives (Prakash & Manhart 2010). The Bo2W project observed that the practices applied in the informal sector follow quite stringent economic considerations. The following examples clearly illustrate this:

- Cables are openly burned to liberate the metal cores (mostly copper, but also aluminium) from the insulation, because cables with insulation are not accepted by scrap metal traders. Although the metal cores could also be liberated by mechanical means (e.g. by pealing with knives or by deploying an engine-driven cable granulator), these options are either much more labour-intensive or require comparably high investment and running costs.

- Fractions which are of no value to informal collectors and recyclers (e.g. CRT-glass, plastics and battery-acid) [2] are disposed of by means that demand the least working time and cost. This means these fractions are haphazardly dumped, mostly very close to dismantling sites. To reduce waste volumes, flammable fractions are periodically burned (mostly plastics). In some cases, such as used lead-acid batteries, non-valuable fractions (in this case the battery-acid) are often disposed of during collection to reduce transport weight.

- Informal recyclers optimise their processes following economic considerations. For example, in 2009 it was common practice in Agbogbloshie, Ghana, to use car tires to light cable fires[3] because waste car tires are widely available for free in Ghana and were therefore long regarded as the best economic option. Informal recyclers then observed that fires with car tires often exceed the melting temperature of aluminium alloys, leading to losses of secondary aluminium. Subsequently, the informal sector in Agbogbloshie stopped utilising cart tires for cable fires and now uses insulation foams from waste fridges instead.

Under such conditions, it is plausible that behaviour cannot be improved by merely imposing bans. In cases where bans exert a negative impact on business activities, it is likely that the opaque nature of the informal system would be used to bypass them. As an example, banning practices might just lead to a temporary or even permanent activity shift to backyards and less prominent recycling clusters.

Difficult enforcement should not, however, be used as an argument to refuse sanction mechanisms in general. Well-targeted sanction mechanisms should be considered in cases where unsound practices are obviously criminal and/or were they have particularly negative impacts on human health and the environment. Amongst others, this includes:

- Illegal imports of e-waste and car waste;
- Open burning of cables, plastics and car tires;
- Uncontrolled drainage of battery acid;
- Violation of environmental and social minimum standards in registered companies.

Generally, it is highly recommended to come-up with a policy framework that not only provides deterrents for polluting practices, but that is coupled with clear incentives for environmentally sound behaviour. In situations where the informal sector is strong, this could be translated into a hand-over system for devices and fractions that are particularly relevant for human and environmental health. In such a system, the best economic option would be to give fractions, such as cables, to a hand-over centre rather than conducting unsound processing like open burning.

Such an incentive-based system nevertheless requires financing beyond the revenues that can be generated from the extracted raw materials. As such financing is not readily available in most developing countries and emerging economies, this aspect is closely linked to the considerations in the next section.

[2] In fact, these fractions mostly have a negative value, as the costs for sound management usually exceed the revenues from such practices (see chapter 3).

[3] Due to flame retardants in cable insulation, other fuels are needed for ignition.

5.4. Financing mechanisms & EPR systems for e-waste

As illustrated in chapter 4 and the beginning of this chapter, environmentally and socially sound recycling is currently not economically competitive with informal recycling practices. As laid-out in section 5.3, it is highly unlikely that in economies with strong informal sectors, level-playing fields can be achieved by solely introducing sanction-mechanisms for non-compliant recycling. In contrast, this study recommends coupling regulations with economic incentives.

In previous sections, it was also laid-out that economic incentives cannot solely be covered by revenues generated from the recovered raw materials, because sound recycling cannot generate significantly high revenues compared with informal recycling operations but instead has higher expenditures for the sound management of negative value fractions and the implementation of other social and environmental standards. Consequently, sound recycling needs access to additional financing, which would position it to successfully compete with informal structures and processes.

A globally accepted means for establishing such a financing mechanism is the concept of Extended Producer Responsibility (EPR). It builds upon the principle that those parties bringing devices onto the market (producers or importers) are held responsible for environmentally sound management. In most cases, EPR systems do not necessarily require producers to manage their own equipment after becoming obsolete; they should more generally handle an amount of devices that is equivalent to those placed on the market in a defined historical time-period.

EPR system designs can vary significantly, and there is no blueprint that can be recommended for all countries. Ghana currently has a draft e-waste bill that – if passed by Parliament – aims at an EPR system where importers of new and used EEE, as well as producers manufacturing in the country, are charged a levy ranging from 0.10 to 5.00 Cedi per device (0.02 € to 1.19 € per device[4]) (EPA Ghana 2013). This levy is aimed to feed a fund that is exclusively dedicated to support sound recycling activities for e-waste. In such a model, government has a regulatory role, leaving implementation of fund management fully to the private sector. Germany follows such a model, where producers unite to form the national register for waste electric equipment (Stiftung ear), which registers producers and coordinates the pick-up and transport of e-waste from municipal collection points according to the existing legal requirements.

The following critical aspects need to be considered when designing an EPR system for e-waste in developing countries and emerging economies:

- The term “producer” should be interpreted in a way that holds all players responsible for equipment placed on the market in the specified jurisdictions. Responsibility would then lie with producers operating within the country as well as the organisations that import equipment manufactured in other countries.
- Importers of EEE and the volumes they import would need to be carefully and comprehensively registered, which might be a challenge in countries whose markets are dominated by many small and medium scale importers.
- As EPR-systems seek to generate financing for sound management, there is an inherent risk for misuse of funds. These risks might be reduced by independently monitoring managed funds, including third party audits. Alternatively, in pure business-driven models (where no funds are channelled through government accounts), the government, possibly

[4] Calculated with the average exchange rate between 01.01.2015 - 31.10.2015 (1 GHC = 0.2373 €).

paired with third-party auditors, should evaluate the success of EPR efforts on the basis of waste volumes managed in an environmentally sound manner.

5.5. Financial support for start-ups

Other important limitations of sound recycling enterprises following the Bo2W philosophy are related to a time lag between investment and running costs on the one hand, and revenues on the other. Recycling enterprises typically earn money only after selling output fractions to downstream markets. In particular, when enterprises follow the approach of directly co-operating with downstream operators (see section 5.1), they receive payments only after sampling and assaying at the downstream processing facilities, which are mostly located oversees[5]. Thus, recycling enterprises need to ensure financing for scrap acquisition, dismantling and sorting, storage, transport and logistics before receiving any return on these expenditures. Practical lessons learned in the pilot implementation in Ghana indicate that the cash-flow gap ranges between 100,000 and 1,000,000 Euros and lasts between 0.5 and 2 years. In most cases in many developing countries and emerging economies, loans for such amounts and time periods are not readily available at suitable conditions[6]. Systematically supporting environmentally sound recycling enterprises following the Bo2W philosophy would also require credit lines tailored to business needs, including moderate interest rates. As an important pre-condition, this would also require banks to develop their knowledge bases on businesses related to recycling, scrap metal trade and waste management.

6. Conclusion

The overall conclusion from the collaborative international Bo2W project funded by the Federal German Ministry of Education and Research is summarized with the following bullet points:

- Despite various limitations, which are particularly related to the current economic disadvantages of sound recycling, the Bo2W concept continues to be the most promising approach for achieving environmentally sound and socially acceptable e-waste and car-waste recycling in developing countries and emerging economies.
- Most importantly, this concept's labour intensive approach suits the needs of most developing countries and emerging economies to generate sound jobs and income opportunities. As an important side effect, such labour intensive recycling is also capable of achieving high recovery rates for various embedded raw materials such as precious metals.
- Labour costs in countries such as Ghana and Egypt (including all costs related to formal employment such as taxes, insurances and payed holidays) allow a comparably deep level of manual dismantling. This has resulted in output fractions of high purity. Comparable high purities are often difficult to be achieved by pure mechanical pre-processing technologies.
- Strategies for promoting environmentally and socially sound recycling sectors in developing countries and emerging economies should refrain from a 'copy-paste' approach to directly implement mechanised recycling technologies of industrialised countries. Instead of

[5] The only types of smelters available in Ghana are for secondary steel and lead from lead-acid batteries. Nevertheless, the latter type of smelters can currently not be recommended as downstream option in Ghana. This is because of obvious shortcomings in the management of hazardous materials and processes and the absence of basic health and safety measures for workers and neighboring communities (Manhart, A. & Schleicher, T. 2015).

[6] As an example, interest rates for such credits are as high as 30-40% p.a. in Ghana, which clearly exceeds the typical profitability of recycling businesses.

promoting “best available technologies” in the sense of the most modern machinery, it is recommended to carefully plan for “best applicable technologies” that fulfil the local needs to create sound jobs and protect human health and the environment.

- Despite these positive characteristics of the Bo2W approach, the practical implementation exercise also revealed significant obstacles. The most important obstacle is competition with informal sectors, which mostly operate by externalising costs. The implementation trial in Ghana revealed that, in spite of the high quality and economic value of many recycling outputs, informal sectors still have a significant economic net advantage. Despite the direct access to downstream markets and despite comprehensive knowledge transfer, our Ghanaian implementation partner cannot successfully compete with the local informal recycling sector in the field of scrap acquisition.

- Sound recycling is currently limited to niche markets in countries such as Ghana and Egypt. These niche markets involve managing waste and scrap from large and multinational enterprises operating locally. Many of these companies have in-house environmental policies and do not want to be associated with potentially polluting waste management practices.

- Depending on local conditions, it is recommended as a first step to extend such niche markets, either by voluntary initiatives or also supported by national regulatory measures. These measures could encourage registered enterprises to dispose of e-waste and car waste only with registered recyclers that can prove sound management of these wastes. Alternatively, regulatory measures would introduce policies demanding sound management of all e-waste and car waste generated by public entities.

- For the remaining e-waste and car waste that is generated by households and small and informal businesses, which likely represent the bulk of the generated volume in many countries, strategies for sound management strongly depend on the economic framework conditions. These framework conditions have to be influenced in a way that sound recycling can successfully compete with informal players. In particular for fractions of high environmental concern (e.g. cables, lead-acid batteries, BFR-plastics), it is recommended to introduce economic incentives so that these materials are channelled to sound recycling facilities.

- To adjust the economic framework conditions, additional financing beyond revenues generated from the sale of recovered materials is needed. Such financing can be realised by introducing the globally accepted principle of extended producer responsibility (EPR) for e-waste. Ghana is currently on the way to introducing an own EPR system for e-waste. Depending on the implementation process, the country has now the potential to take a pioneering role in the African context.

- Due to the increasing and tremendous challenge of hazardous e-waste and car waste practices in many developing countries and emerging economies, a coordinated international funding process should be initiated. In such a process, the comparably low costs of avoiding the emissions of hazardous substances from crude recycling (e.g. the emissions of dioxines and furanes during the open burning of cables) should also be considered. Thus, international communities should elaborate on the feasibility of a clean-development mechanism for such hazardous emissions.

- Considering that in a few years most of the world’s e-waste and car waste is projected to be generated in developing countries and emerging economies, managing these wastes

becomes an ever-increasing strategic issue. Efforts should strive to not only minimise adverse effects on human health and the environment, but to also close global material cycles and to maximise recycling rates of metals and other recyclable resources.

7. Annexes – List of Bo2W project sub-reports and other Bo2W publications

The following Bo2W project sub-reports are available on www.resourcefever.org:

a) Global Circular Economy of Strategic Metals (Bo2W) - Chapter Ghana (April 2014)

b) Global Circular Economy of Strategic Metals (Bo2W) - Chapter Egypt (July 2014)

c) Recycling options for waste CRT glass (April 2014)

d) Recycling options for WEEE plastic components (October 2014)

e) Bo2W: Legal and institutional requirements in Ghana (October 2014)

f) Recycling of Hard Disk Drives - Analysing the optimal dismantling depth for recyclers in developing countries and emerging economies (November 2015)

A Bo2W film addressing the lead-acid battery recycling in Ghana is published on

http://www.oeko.de/en/up-to-date/2015/new-film-on-the-recycling-of-lead-acid-batteries-in-ghana/

The following Bo2W posters are available in English, French, Arabic, Twi & Hausa on www.resourcefever.org:

a) Dismantling CRT

b) Dismantling Desktop Computer

c) Packaging Lead Acid Batteries

Five Bo2W presentations from the Bo2W closing event (24 September 2015) are available on www.resourcefever.org

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