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Recycling of Hard Disk Drives – Analysing the optimal dismantling depth for recyclers in developing countries and emerging economies

Global Circular Economy of Strategic Metals – the Best-of-two-Worlds Approach (Bo2W)

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Disclaimer:

All figures and calculations in this report are based on data collected in spring and summer 2013. As some of these data are subject to variations over time (e.g. scrap metal prices, labor costs), both, data and results might not necessarily reflect the current conditions.

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1. Introduction

Hard disk drives occur in most end-of-life desktop and notebook computers, either as 3.5 inch model (desktops) or 2.5 inch model (notebooks). While the assembly of hard disk drives is quite compact, it consists of various materials that are of interests for recycling enterprises and refineries (see Picture 1-2). Nevertheless, hard disk drives are often designed in a way that makes it difficult to effectively separate and completely liberate the containing materials for recycling (cover that is glued onto the case, various screws of unconventional format…). While in industrialised countries, hard disk drives are often shredded either together with the end-of-life computers or after separation, manual dismantling often allows generating output fractions of higher purity and thus higher value for recycling (Gmünder 2007, Chancerel & Rotter 2009, Salhofer & Spitzbart 2009). In addition, such manual operations enable the recovery of the containing rare earth magnets. These magnets are currently not separated with mechanical pre-processing technologies and are mostly sorted into the ferrous metals fraction where rare earths (Neodymium, Dysprosium) are diluted and lost for recycling.

Nevertheless, pre-processing enterprises need to find a balance between costs of operations and economic return. In the case of manual dismantling of hard disk drives, this balance is largely determined by labour costs on the one side and scrap-metal prices on the other side. Thus, pre-processors focusing on manual dismantling as those following the Bo2W-philosophy have to decide carefully to what extent manual labour is utilised. In the case of hard disk drives, this decision is particular difficult for the following reason:

- Manual dismantling of hard disk drives requires quite unconventional tools, which are often not widely available in developing countries and emerging economies (e.g. size 9 Torx-screwdrivers).
- Specialised recyclers buy hard disk drives at wholesale prices. Thus, there is an easy-to-use alternative to manual dismantling which does not require any own investments in machinery.
- Although the rare earth magnets of hard disk drives have a significant intrinsic material value[1], there is currently no developed market for scrap magnets. Although this situation might change in the future, the economic gains of manual recovery of rare earth magnets are still unknown.

In order to support the decision-making of recycling enterprises operating in the Ghanaian and Egyptian context, a hard disk drive dismantling trial was carried out. This trial aims to answer the following questions:

- Does the higher resource recovery of manual dismantling economically enable a full manual dismantling of hard disk drives presuming average resource prices as of 2013 and wage levels in Ghana / Egypt?
- What price level is needed for rare earth magnets to economically justify full manual dismantling of hard disk drives in Ghana / Egypt?

[1] According to Buchert et al. (2012), the rare earth magnets of voice coil accelerators in Hard Disk Drives contain up to 29% Neodymium and 2% of Dysprosium. Assuming an average magnet weight of 14.5 g per Hard Disk Drive (see Table 2-1) and a metal-price level as of September 2013 (Nd-metal with 99% purity: ~ 100 US$/kg; Dy-metal with 99% purity: ~ 715 US$/kg) this results into an intrinsic material value of more than 0.60 US$ for the magnets of one Hard Disk Drives.

- What is – from an economic perspective – the optimal dismantling depth for hard disk drives in Ghana / Egypt?

In order to provide answers to these questions, three scenarios were defined and compared:

Scenario 1 - No dismantling of HDD

The hard disk drives are sold to specialised companies offering a wholesale price for (data wiped) devices.

Scenario 2 - Dismantling of printed wiring board.

The printed wiring boards are manually unscrewed and separated from the devices. The printed wiring boards are delivered to a pyro-metallurgical smelter to recover precious metals, copper and other metals. The remaining hard disk drives are sold to specialised companies offering a wholesale price for (data wiped) devices.

Scenario 3 - Full manual dismantling of HDD

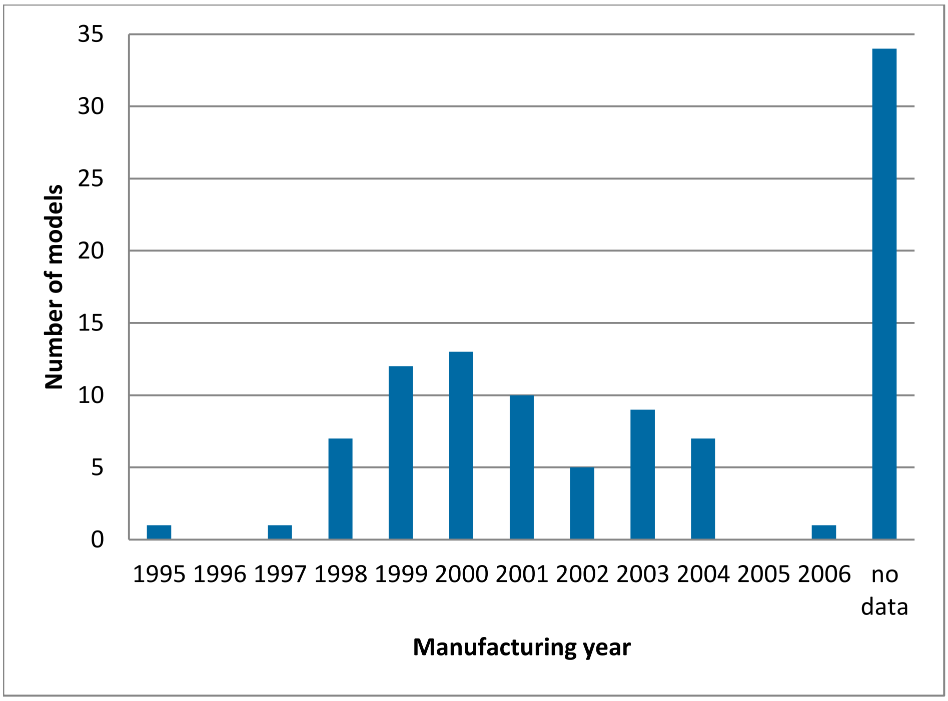
The hard disk drives are manually dismantled into the following fractions: Printed wiring boards, aluminium-parts, steel-parts, rare earth magnets (demagnetised). Each fraction is sold to downstream markets separately (see Picture 1-2).

The scenarios were compared using data retrieved from a dismantling trial of 100 hard disk drives of the 3.5 inch format. The trial was carried out in summer 2013 in the premises of City Waste Recycling in Accra, Ghana. The hard disk drives came from e-waste collection carried out by the informal sector in Kumasi, Ghana. The manufacturing year of the hard disk drives ranged between 1995 and 2006[2] (see Figure 1-1) and the storage capacity between 1 GB and 854 GB[3] (see Figure 1-2). 37 hard disk drives were delivered without printed wiring board, meaning that these components were already dismantled prior to delivery to City Waste Recycling. Thus, the full dismantling test could only be carried out on 63 models. Nevertheless, the models without printed wiring boards were also dismantled and the missing data was completed using average values from the dismantling of the devices with printed wiring board.

[2] The manufacturing year was indicated on 66 models. For the remaining 34 models, the manufacturing year is unknown.

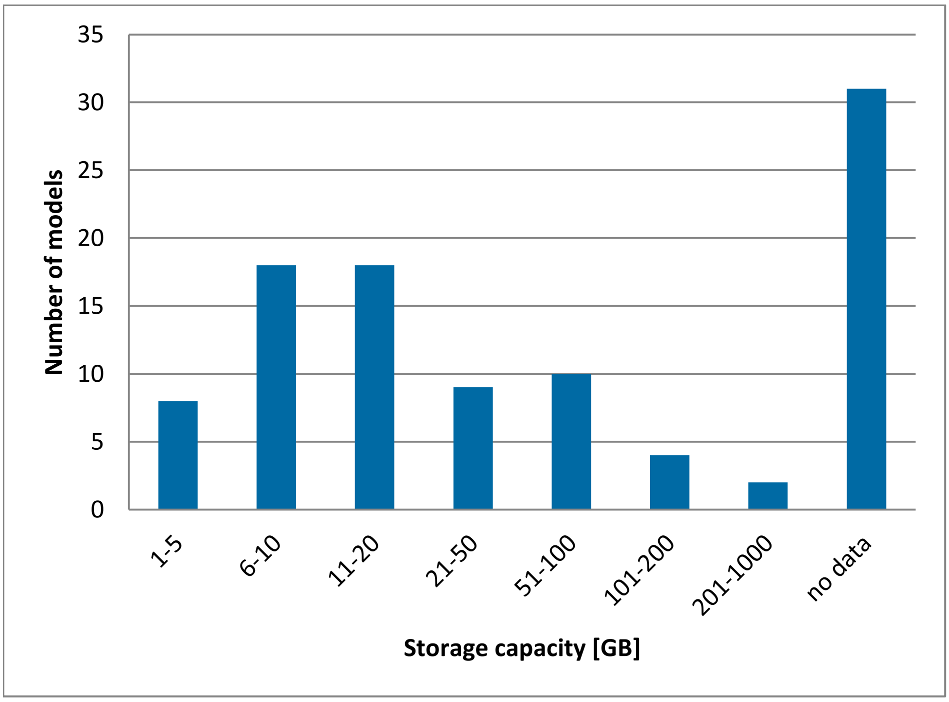
[3] The storage capacity was indicated on 69 models. For the remaining 31 models, the storage capacity is unknown.

Figure 1-1: Manufacturing years of hard disk drives of the dismantling trial



Source: Bo2W-Project survey, 2013

Figure 1-2: Storage capacities of hard disk drives of the dismantling trial



Source: Bo2W-Project survey, 2013

Dismantling was carried out by trained personal permanently employed at City Waste Recycling. For dismantling, pliers and screwdrivers of various sizes (flat, star, Torx 5-10) were used. Dismantling was carried out on a standard work bench equipped with a bench vice, which could be used optionally by the dismantling personal. In addition, a power drill was available for cases were the screws could not be opened with screwdrivers. This option was chosen for one model featuring damaged screws. All other models could be opened and dismantled using screw drivers and pliers only.

Dismantling was carried out by one person. Another person gauged the dismantling time. After dismantling of each model, the various parts and fractions were weighted and all data entered into an Excel-sheet.

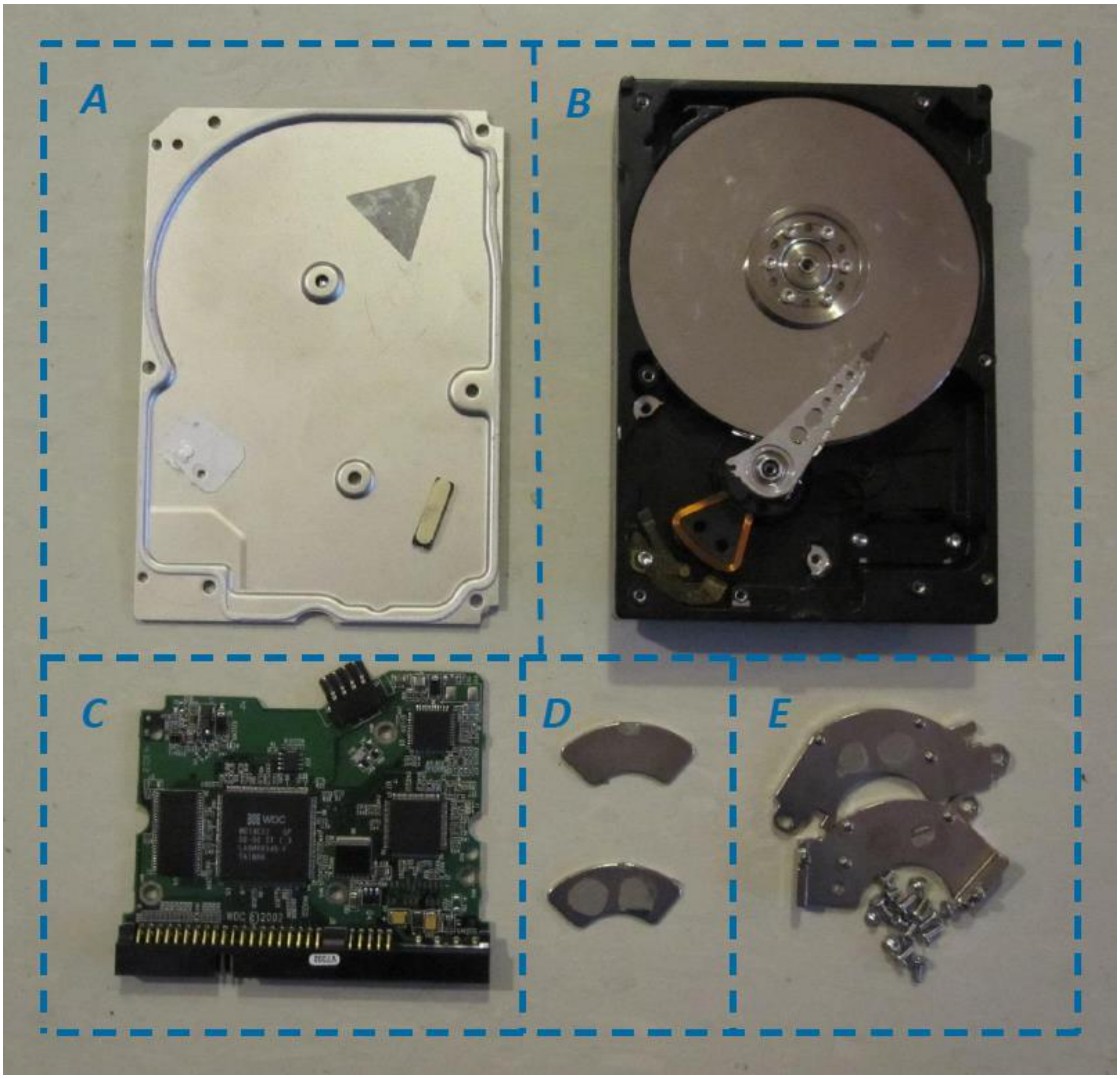
Picture 1-1: Impression of the hard disk drive dismantling trial carried out at City Waste Recycling in Accra in summer 2013

Source: Bo2W-Project

Time measurement started when a new hard disk drive was placed on the work bench. Thus, the measured working time also includes the time needed to choose the right tools and screw driver sizes. As first dismantling step, the printed wiring board was unscrewed. Once this was accomplished, a first interim time was taken and entered into the Excel-sheet. This interim time was used for modelling scenario 2. The total time was taken after the hard disk drive was dismantled into the following fractions:

- Aluminium parts (some lids, case with platters and voice coil assembly)
- Printed wiring board
- Magnets and magnet shoes (attached to each other)
- Steel parts (some lids, screws)

Picture 1-2: Dismantling depth of the hard disk drive dismantling trial (scenario 3): A: Lid; B: Case with platters and voice coil assembly; C: Printed wiring board; D: Magnets; E: Magnet shoes and other steel parts



Source: Bo2W-Project

After taking the total dismantling time, all fractions were weighted. In addition, the platters were physically strained to identify the type of base material[4]. 98 models featured platters based on

[4] The base material of platters of 3.5 inch hard disk drives is mostly aluminium, while platters of 2.5 inch models are mostly made from glass (Buchert et al. 2012). The described strain-test was applied in order to verify this information for all models.

aluminium as main material. Two models featured glass-based platters and did not resist the strain-test.

The rare earth magnets were demagnetised and separated from the steel shoe by heating over a gas-flame. This working step was not taken into account in the measurement of the dismantling time. This is because the heating and sorting step can be conducted at significantly higher efficiency when carried out for a large number of magnets at the same time. Thus, the time-requirements for this separation step were estimated on a generalised basis and added to the total dismantling time of scenario 3 (see section 3).

2. Material compositions and price levels

In Table 2-1, the average material composition of the dismantled 3.5 inch hard disk drives is displayed.

Table 2-1: Average material composition of the hard disk drives of the dismantling trial

Fraction	Comments	Average weight	Weight percentage
Printed Wiring Board		35.7 g	7.0 %
Aluminium parts	Case, Al-platters, Al-lids, voice-coil.	398.4 g	78.1 %
Steel parts	Steel-lids, magnet-shoes	61.3 g	12.0 %
Rare earth magnets		14.5 g	2.8 %
Total		**509.8 g**	**100 %**

Source: Bo2W-Project survey, 2013

Table 2-2 shows the scrap prices and downstream markets applicable in the Ghanaian context in summer 2013[5].

[5] These figures are derived from a market survey carried out by City Waste Recycling Ltd. aiming to retrieve realistic price values for internal cost-benefit calculations. While, the price for steel is based on the scrap purchase of steel-plants in Tema (Ghana), the price for printed wiring boards was calculated based on measured metal concentration of the retrieved HDD-boards, average world market prices for these metals in H1 2013 and terms and conditions offered by Umicore Precious Metals Refining. The price for scrap-aluminium was estimated based on information from EU-recyclers experienced in the secondary aluminium market in the EU. The price for scrap rare earth magnets is indicative and not based on a developed market for such scrap types.

Table 2-2: Scrap prices and downstream markets for fractions retrieved from hard disk drive dismantling

Fraction	Scrap prices as of summer 2013[6]	Location of downstream market	Export/import notification required
Printed Wiring Boards	27.33 US$/kg	EU	No
Aluminium parts	1.5 US$/kg	EU	No
Steel parts	0.3 US$/kg	Ghana	No
Rare earth magnets	4.0 US$/kg	EU	No

Source: Bo2W-Project survey, 2013

While the prices of Table 2-2 were used to model scenario 2 and 3, the wholesale prices for complete hard disk drives as well as for hard disk drives without printed wiring boards were gathered from a European pre-processing company (see Table 2-3).

Table 2-3: Wholesale prices for data wiped end-of-life hard disk drives (with and without printed wiring board) in the EU in the first half of 2013[7].

Fraction	Price [Euro]	Price [US$]	Location of downstream market	Export/import notification required
Hard Disk Drives complete	1500 Euro / t	1951.0 US$ / t	EU	No
Hard Disk Drives without PWBs	1050 Euro / t	1365.7 US$ / t	EU	No

Source: Bo2W-Project survey, 2013

These data were used to calculate the economic revenues from in the three scenarios, which are displayed in Table 2-4 to Table 2-6.

Table 2-4: Calculation of the economic revenues in scenario 1 (no dismantling of HDD)

Fraction	Average weight per device	Scrap prices as of summer 2013	Average scrap prices per device
Hard Disk Drive with PWB	509.8 g	1.951 US$ / kg	0.99 US$
Total			**0.99 US$**

Source: Bo2W-Project survey, 2013

6 Price-levels for printed wiring boards represent an average price for H1 2013.

7 Exchange rate: 1 Euro = 1.3007 US$ (Average exchange rate between 01.01.2013 and 30.06.2013).

Table 2-5: Calculation of the economic revenues in scenario 2 (dismantling of PWB)

Fraction	Average weight per device	Scrap prices as of summer 2013[8]	Average scrap prices per device
Printed Wiring Board	35.7 g	27.33 US$/kg	0.98 US$
HDD without PWB	474.1 g	1.3657 US$/kg	0.65 US$
Total			**1.63 US$**

Source: Bo2W-Project survey, 2013

Table 2-6: Calculation of the economic revenues in scenario 3 (full dismantling of HDD)

Fraction	Average weight per device	Scrap prices as of summer 2013[9]	Average scrap prices per device
Printed Wiring Boards	35.7 g	27.33 US$/kg	0.98 US$
Aluminium parts	398.4 g	1.5 US$/kg	0.60 US$
Steel parts	61.3 g	0.3 US$/kg	0.02 US$
Rare earth magnets	14.5 g	4.0 US$/kg	0.06 US$
Total	**509.8 g**		**1.66 US$**

Source: Bo2W-Project survey, 2013

3. Labour costs

The labour costs in City Waste Recycling are based on the following framework conditions:

- Daily working hours: 7
- Working days per week: 6
- Number of paid days-off per year: 15
- Number of paid public holidays per year: 13 (average)
- Standard remuneration per day: 4.00 US$
- Employer’s contribution to health insurance and old age pension: +13,5% of standard remuneration
- Extra payment at the end of the year: One month’s salary

Based on this data, the total labour costs per working day are 5.40 US$ and 0.77 US$ per hour which is a fair level for Ghanaian workers in the recycling sector.

8 Price-levels for printed wiring boards represent an average price for H1 2013.

9 Price-levels for printed wiring boards represent an average price for H1 2013.

The time measurements in the dismantling trial retrieved the following average values:

- Scenario 1: 0:00 Minutes
- Scenario 2: 0:21 Minutes
- Scenario 3: 2:06 Minutes

As these measurements did not account for supporting work necessary for the facility's operation (e.g. preparation and sorting of tools, cleaning of workplace, transfer of generated fractions into storage), a 20% increase of working time was considered in the calculation of labour costs. Another 10% were added for scenario 3 in order to account for the demagnetisation and separation of magnets.

The labour requirements for transport (e.g. loading into containers, filling out documents) were not considered in the scenarios. This can be justified by the fact that these efforts are comparable in all scenarios. Even in scenario 3, where four output fractions are generated and sold, this does not significantly increase these efforts, as three of these fractions (steel, aluminium, PWBs) are standard fractions and can managed in parallel to other dismantling outputs.

Table 3-1: Calculation of labour costs in the three scenarios

Scenario	Measured dismantling time per HDD	Time-adder	Calculated dismantling time per HDD	Calculated labour costs per HDD
Scenario 1 (no dismantling)	0:00 minutes	+20%	0:00 minutes	0.00 US$
Scenario 2a (dismantling PWB)	0:21 minutes	+20%	0:25 minutes	0.01 US$
Scenario 3a (full dismantling)	2:06 minutes	+30%	2:44 minutes	0.04 US$

Source: Bo2W-Project survey, 2013

It can be argued that the dismantling times used in Scenario 2 and 3 are only applicable in a test environment, as these conditions can motivate dismantling personnel to achieve above average dismantling times. Thus, it can be argued that the gauged dismantling times cannot be maintained over longer time-periods. Therefore, the impact of longer dismantling-time is evaluated in a sensitivity analysis. Therefore, it is assumed that the scenario 3 dismantling requires 5:00 minutes per HDD. This time was achieved in comparable HDD dismantling test by Hitachi (Nemoto et al. 2011). For scenario 2, it is assumed that dismantling time might also be longer by around 83% resulting in 0:46 minutes.

Table 3-2: Calculation of labour costs for the sensitivity analysis

Scenario	Assumed upper boundary for dismantling time per HDD	Calculated upper boundary for labour costs per HDD
Scenario 1 (no dismantling)	0:00 minutes	0.00 US$
Scenario 2b (dismantling PWB, conservative dism. time)	0:46 minutes	0.01 US$
Scenario 3b (full dismantling, conservative dism. time)	5:00 minutes	0.06 US$

Source: Bo2W-Project survey, 2013

4. Transport costs

Transport of recyclable materials from a Ghanaian dismantling facility to a downstream market is a major cost factor in all recycling activities. Generally, it is assumed that all exports of output fractions are organised with 20-feet sea freight container. In addition, it is assumed that one container is on average filled with 7 t of material.

This results in the following average cost-structure for scrap exports:

Table 4-1: Overview of transport costs for container exports (sources: practical experiences of project partners)

Cost item	Costs per 20-feet-container	Costs per metric ton
Loading of container (labour costs + packaging materials)	200 US$	28.57 US$ / t
Transport of 20' container to Tema (harbour)	400 US$	57.14 US$ / t
Fees for forwarding company	700 US$	100.00 US$ / t
Transport from Tema to EU smelter	975 US$	139.29 US$ / t
Sum	**2275 US$**	**325.00 US$ / t**

Source: Bo2W-Project survey, 2013

For fractions, which can be treated locally (in this case only steel parts), the transport is assumed to sum up to 85.8 US$ / t (sum of container transport costs for loading and transport to Tema) as the Ghanaian secondary steel plants are all located in the port city of Tema.

Table 4-2 gives an overview over the masses that require exports and those that can be treated within Ghana in the three scenarios. The table also gives a net cost calculation for the total transport costs for one HDD under each scenario:

Table 4-2: Calculation of transport costs in the three scenarios

Scenario	Mass that requires export [per HDD]	Mass of fractions with downstream markets in Ghana [per HDD]	Transport costs per HDD
Scenario 1 (no dismantling)	509.8 g	0 g	0.1657 US$
Scenario 2 (a & b) (dismantling PWB)	509.8 g	0 g	0.1657 US$
Scenario 3 (a & b) (full dismantling)	448.5 g	61.3 g (steel parts)	0.1510 US$

Source: Bo2W-Project survey, 2013

5. Results & interpretation

The calculation in Table 5-1reveals that the scenarios 2 and 3 are clearly preferable compared to scenario 1 (no dismantling).

While scenario 3 (full manual dismantling) seems to be preferable to scenario 2 (dismantling of PWB) under Ghanaian conditions, this conclusion might be misleading for the following reasons:

- The used price level for scrap rare earth magnets is indicative only. Although this indicative value contributes only to 3.4 % to the total resource revenues of scenario 3 (US$ 0.06 per HDD), deviations can alter the overall picture of this scenario analysis.
- The price levels for the economic revenues of scenario 3 (see Table 2-6) are average values and require real life tests. In particular for aluminium, the price strongly depends on scarp quality and delivered volumes. Thus, final recommendations can only be made after first deliveries of scrap aluminium to downstream markets have been made.

Furthermore, economic decisions in favour of scenario 2 or 3 also need to take other company activities into account, which might offer better potential improvement. These opportunity costs cannot be accounted for in this exercise and need to be judged on by the management of the recycling enterprise.

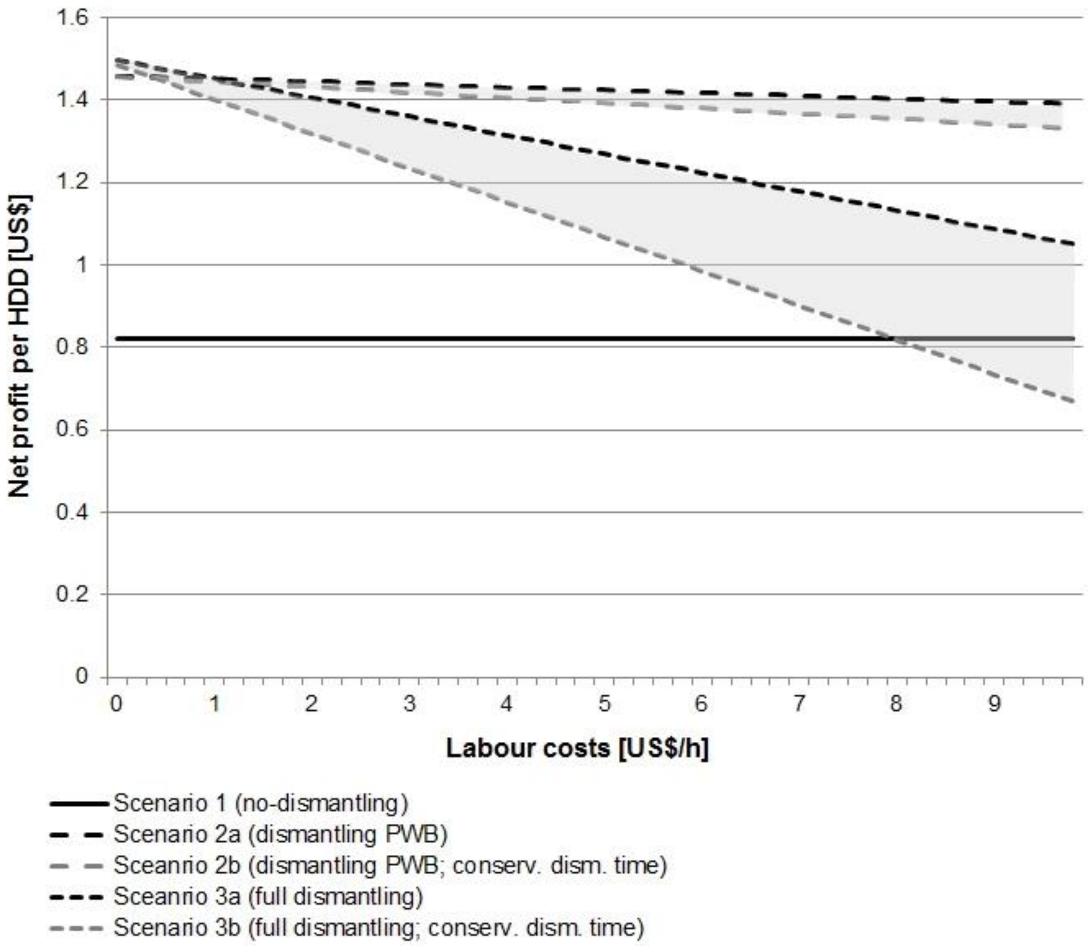
Table 5-1: Calculation of profits in the three scenarios and sensitivity scenario with conservative dismantling time (scenario 3b)

Scenario	Labour costs per HDD	Transport costs per HDD	Resource revenues per HDD	Net Profit per HDD
Scenario 1 (no dismantling)	0.00 US$	0.17 US$	0.99 US$	0.82 US$
Scenario 2a (dismantling PWB)	0.01 US$	0.17 US$	1.63 US$	1.45 US$
Scenario 2b (full dismantling, conservative dism. time)	0.01 US$	0.17 US$	1.63 US$	1.45 US$
Scenario 3a (full dismantling)	0.04 US$	0.15 US$	1.66 US$	1.47 US$
Scenario 3b (full dismantling, conservative dism. time)	0.06 US$	0.15 US$	1.66 US$	1.45 US$

Source: Bo2W-Project survey, 2013

In order to give some orientation how this analysis would translate under different socio-economic conditions (e.g. in other developing countries and emerging economies), a sensitivity analysis was carried-out. In this analysis, the transport costs and resource revenues were assumed to be static and at the same levels as displayed in Table 5-1. The labour costs were varied between 0.30 and 10.00 US$/h for all scenarios. The results are displayed in Figure 5-1. It shows that the full dismantling scenarios are only competitive in the very low labour costs segment (roughly below 1 US$/h). In contrast, dismantling of PWB can be promoted in all situations with mid- and even high labour cost situations.

Figure 5-1: Results of sensitivity analysis with varying labour costs



Note: All calculations are based on real or indicative scrap prices as of H1 2013. Variations of these prices as well as of the other influencing factors (namely dismantling time, material composition and transport costs) may significantly alter the results.

Source: Bo2W-Project survey, 2013

Referring to the research questions in the beginning of this section, we can conclude the following.

- From an economic perspective, manual dismantling of hard disk drives (both scenarios: dismantling of PWB and full dismantling) are clearly preferable to no manual dismantling in the Ghanaian context. This is also the case in situations where labour costs range below around 8 US$/h. For situations with higher labour costs, dismantling of PWBs can still be competitive assuming high dismantling efficiencies.

- The resource recovery does enable a full manual dismantling of hard disk drives in the Ghanaian context, presupposing labour costs and scrap prices as of H1 2013. Nevertheless, full manual dismantling is economically not necessarily superior to a less deep dismantling option (dismantling the PWBs, sending the remaining HDD to specialised pre-processing companies in Europe). This is particular the case for situations where labour costs are above ~ 1 US$/h.

- The analysis revealed that the price-level of scrap rare earth magnets has a comparably minor impact on the total economic picture of hard disk drive management. Here, the PWB and aluminium-fraction are far more important. Nevertheless, the price-level for rare earth magnets can serve as crucial additional reason to conduct full manual dismantling of hard disk drives. Thus, high prices for scrap rare earth magnets might be able to motivate full manual dismantling of HDDs – at least in regions with comparable labour cost structure as in Ghana.

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